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Shop Drawings

Measurements, Drilling, and Appliances

286 ILLUSTRATIONS

Prepared Under Supervision of

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READING WORKING DRAWINGS
MEASURING INSTRUMENTS
PRECISION MEASURING INSTRUMENTS
DRILLING
GENERAL APPLIANCES AND PROCESSES

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

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READING WORKING DRAWINGS

REPRESENTATION OF OBJECTS

WORKING DRAWINGS

GENERAL PRINCIPLES

1. A **drawing** is a representation of an object by means of lines. A **mechanical drawing** consists of one or more views of an object, so made and arranged as to show the shape of the object, its dimensions, the way in which its parts are put together, and the material or materials of which it is made. Mechanical drawings form a universal language, so far as engineers and mechanics are concerned. A mechanical drawing that is used as a guide in making the parts of a machine or in putting those parts together properly is called a **working drawing.**

2. Comparison of Perspective and Mechanical Drawings.—A drawing made to show the shape of an object by a single view is called a **perspective drawing**. It represents the object as it would appear to the eye, or as in a photograph; but though it shows clearly the general form of the object, it cannot be used successfully as a working drawing, because it does not show all the dimensions of the object in their true lengths. A mechanical drawing does not represent an object as it would appear to the eye, but it is the kind of drawing that is universally used as a working drawing. The

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reasons for its adoption are that it may be made more easily than a perspective drawing, it shows the correct shape of the object, and it gives the true dimensions of the various parts. Perspective drawings, however, show the form of an object so well that they are used considerably in this Section in connection with working drawings.

3. Reading of Drawings.—The reading of working drawings must not be confused with the art of making the drawings. In order to read a working drawing, that is, to understand clearly just what the drawing is intended to show, it is necessary to know what is meant by each different kind of line, by the arrangement of the different views, and by the lettering, abbreviations, signs, etc. used on the drawing. This is rendered easier if the reader is also familiar with mechanical terms and shop methods. In order to make a drawing, however, the draftsman must know, in addition to all the foregoing matters, how to use drawing instruments. The purpose of this Section is to explain how to read working drawings, and not how to make them; hence, it is not necessary to know anything about the use of drawing instruments.

BLUEPRINTS

4. Purpose of Blueprints.—The working drawing prepared by the draftsman is made on heavy paper, with a lead pencil. If this original drawing were sent to the shop to be used as a working drawing from which to construct the piece of work, it would soon become soiled or torn, and the pencil lines would be rubbed out to such an extent that it would be useless for the desired purpose. It would then be necessary to repeat the work of the draftsman and make a fresh drawing. To avoid this unnecessary labor and expense it is customary to use blueprints as the working drawings in the shop, and to preserve either the original drawing or a copy of it. The common form of blueprint is a sheet of paper one side of which is blue and on which side, in white lines, is an exact duplicate of the original working drawing. Blueprints of this kind have the advantage of being cheaply and quickly

made; thus, if one becomes so soiled or torn that it is hard to read, it can easily be replaced by a new print.

5. Making a Blueprint.—The first step in making a blueprint of a drawing is to make a *tracing* of the drawing. The pencil drawing is covered with a sheet of transparent paper or cloth, known as *tracing paper* or *tracing cloth*, and on this transparent sheet a copy, or tracing, of the original drawing is made with black ink. This tracing is then an exact duplicate of the drawing, and contains all the views of the object, the notes, title, dimensions, scale, and any other necessary marks. The tracing is next laid flat on a sheet of blueprint paper, the face of which is coated with a chemical solution that, when dry, gives the paper a yellowish color. The chemical coating is very easily affected by light. Therefore, the blueprint sheet, with the tracing on it, is exposed for a short time to electric light or to the sun after which the tracing is removed and the blueprint paper is washed in water, and dried. Wherever a black line was shown on the tracing, a white line now appears on the blueprint, and the blank, or white, spaces as seen on the tracing, appear blue on the print. This print is in every detail an exact duplicate of the tracing. Any desired number of prints may be made from the tracing.

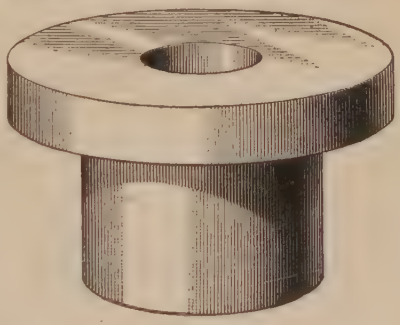


FIG. 1

VIEWS OF AN OBJECT

6. Elementary Working Drawing.—A perspective drawing of a plain bushing is shown in Fig. 1, and a working drawing of the same piece, in Fig. 2. The working drawing shows two views, that in (*a*) being a *side view* and that in (*b*) a *plan*, or *top view*. The side view, sometimes called the *side elevation*, shows the piece as it would appear when looked at squarely from one side; or, it shows the outlines of the piece as they would appear if the piece were stood upright

against a sheet of paper held vertically and its form were traced against the sheet. The plan, or top view, shows the appearance of the piece when looked at from a point directly above.

7. The dimensions are marked on the working drawing, Fig. 2, so that the two views and the dimensions tell the exact shape of the piece and the size of each part of it. The sign ″ written above and to the right of each dimension means inches; thus, $1\frac{1}{2}''$ means $1\frac{1}{2}$ inches. The plan shows three circles, one of which is dotted. The circle *a* is the top of the hole that runs through the piece from top to bottom, and in the side view this hole is indicated by the two parallel dotted lines *b* and *c*, which run from top to bottom and are marked as being $\frac{5}{8}$ inch apart; therefore, it is understood that the hole is round and is $\frac{5}{8}$ inch in diameter. The circle *d* is the top view of the flange, or collar, *e* and shows that the flange is round; it is 2 inches in diameter.

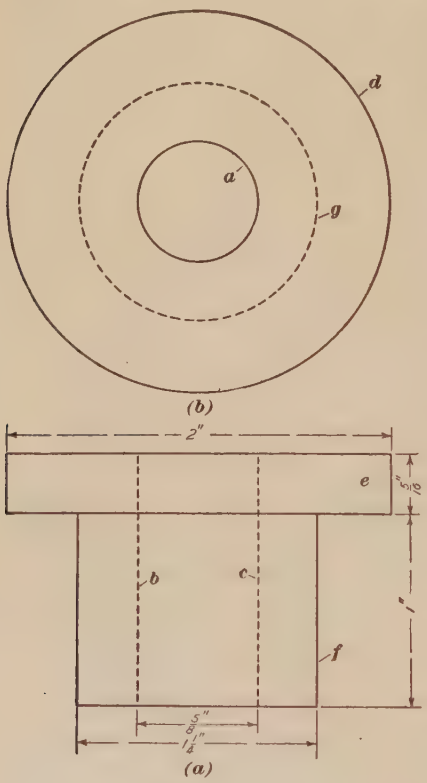


Fig. 2

The thickness of the flange is $\frac{5}{16}$ inch, marked in the side view. The part *f* that projects below the flange is 1 inch long, as marked in the side view, and is indicated in the plan by the dotted circle *g*. This circle indicates that the part *f* is round, also, and the side view gives $1\frac{1}{4}$ inches as the diameter of it.

Thus, this working drawing gives all the information needed to enable the workman to make the bushing.

8. Number of Views on a Working Drawing.—The purpose of the working drawing is to furnish enough information as to the shape and size of an object to enable the workman to make it correctly. The number of views to be given on the working drawing depends on the nature of the object. Usually two or three views are enough to show the form and all the necessary dimensions, and in some cases only one view is needed; on the other hand, if the object is intricate or of peculiar shape, four or more views may be required. In Fig. 2, for example, two views show all that is required. In Fig. 3, one view gives the necessary information for making a pin having the dimensions indicated. The use of the abbreviation *Dia.*, meaning diameter, shows that the head of the pin and the shank are round, and not square or of some other shape.

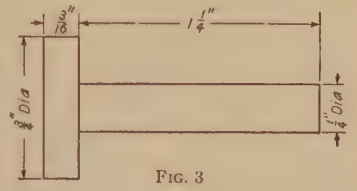


FIG. 3

9. Arrangement of Views.—The different views of the object are arranged on the working drawing according to either the American or the British system. In the American system, one of the views is taken as the principal view and the others are grouped around it, each being placed next to the side that it represents. This may be shown more clearly by an example. In Fig. 4 is illustrated a wedge-shaped block, and in Fig. 5, a mechanical drawing of the block showing five views arranged according to the American system. The front view (*a*) is taken as the central view, and the others are placed around it. Thus, the view (*b*) of the right-hand face is placed at the right, and the view (*c*) of the left-hand face at the left. The top view, or plan, (*d*) is

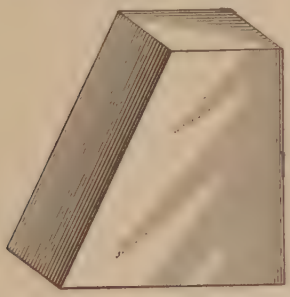


FIG. 4

put above the front view and the bottom view (*e*) is placed below. In this way, each view is at that side, or face, which it represents.

10. The American system of arranging the views on a mechanical drawing is often called the *third-angle method*, and the British system is called the *first-angle method*. The British method, which is used in Great Britain and on the European continent, is the opposite of the American practice. For instance, in the British system, the view (*b*) of the right-hand face of the block, Fig. 5, would be placed at the left of the front view (*a*), and the view (*c*) of the left-hand face would be placed at the right of view (*a*). Similarly, the top view would be placed below the front view and the bottom view would be placed above it. The five views shown in this drawing are not necessary, as the shape of the block could be fully indicated by two views, namely, the front view (*a*) and the top view (*d*). However, the illustration serves to show the positions in which the several views should be placed when more than one or two are necessary.

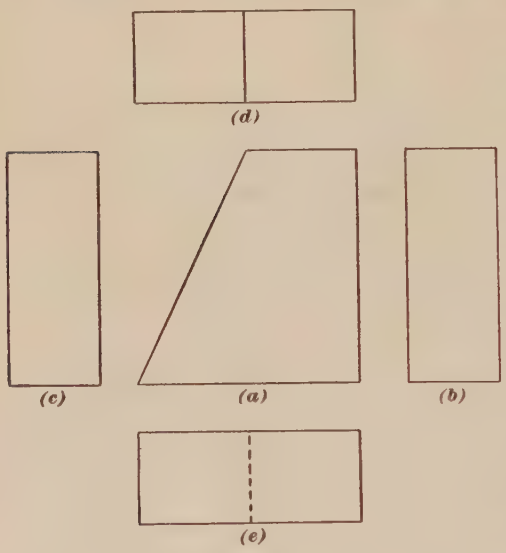


FIG. 5

11. Relation of Views.—The relation that the different views of an object bear to one another, when arranged according to the American system, may be made clearer by the method illustrated in Fig. 6. In (*a*) is shown a plate of glass *a* beveled at the edges and hinged to four similar glass plates *b*, *c*, *d*, and *e*.

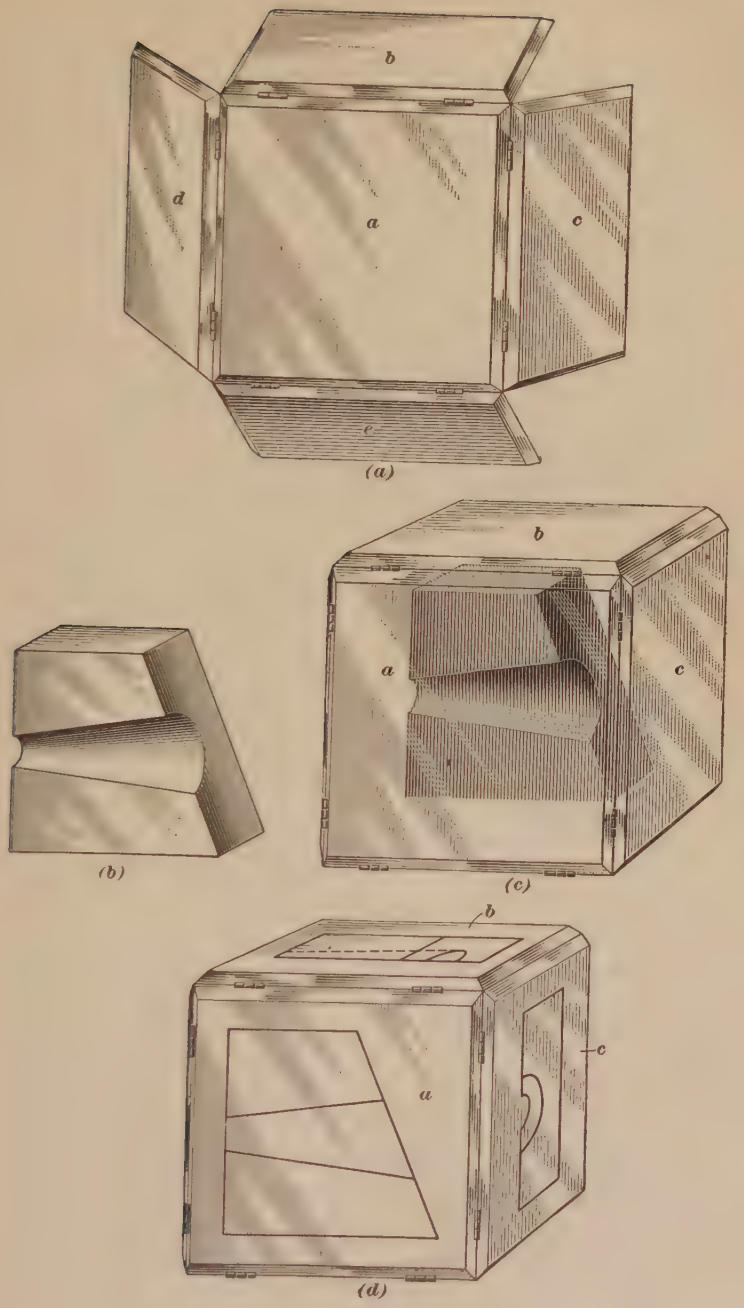


FIG. 6

These five plates may be folded so as to form a box, or they may all be opened out flat. In (*b*) is shown a wedge-shaped block with a tapered groove in one side. Suppose that this block is placed inside the box formed by the framed plates in (*a*), as shown in (*c*). Next, suppose that the wedge-shaped block is viewed through each of the plates *a*, *b*, *c*, etc., from the front, top, sides, and bottom, and that on each plate is drawn the

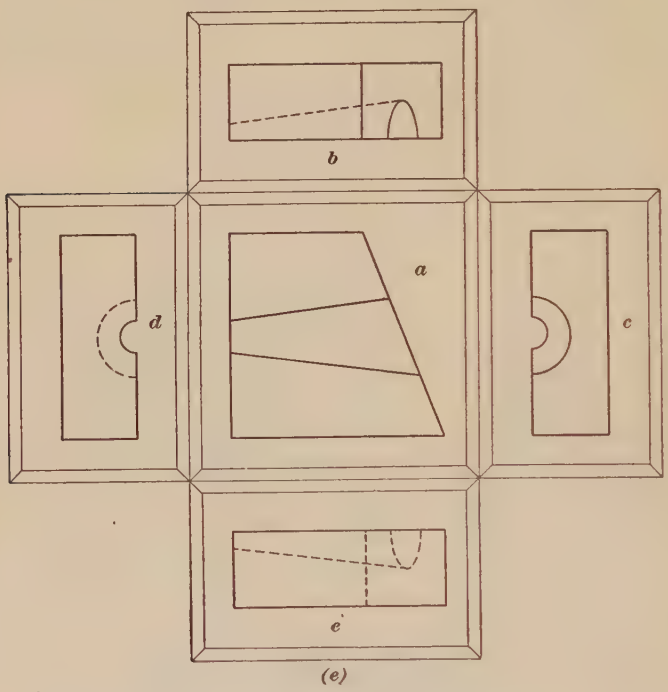


FIG. 7

outline of the block as it appears when viewed squarely through that plate. The views of the block as seen through the plates *a*, *b*, and *c* are shown in (*d*). Now, when all the views have been drawn, suppose that the four hinged plates *b*, *c*, *d*, and *e* are folded out until they come flush with the central plate *a*, as shown in Fig. 7. The five views of the object will then be in their correct relative positions.

12. Projectors.—The draftsman, of course, does not obtain the various views by the method shown in Figs. 6 and 7. Instead, he uses a series of horizontal and vertical lines, called *projectors*, to transfer points and lines from one view to another. This is more clearly illustrated in Fig. 8. Suppose that a drawing is to be made of the grooved wedge-shaped block shown in (*a*). The drawing may then be done as shown in the front view (*b*), the two end views (*c*) and (*d*), the top view (*e*), and the bottom view (*f*). The outline *a b c d*, view (*b*), is the front face *a b c d* of the block shown in (*a*), and the lines *e f* and *g h* are the straight edges of the groove. To construct the end view (*c*), the lines *a b* and *d c* are extended to the right, and between them is drawn the vertical line *b c*, which represents the edge *b c* of the original block. Then, along the top horizontal line a distance *b i* is laid off equal to the thickness of the block, and the vertical line *i j* is then drawn. From the points *e*, *f*, *g*, and *h*, in the view (*b*), horizontal projectors are drawn toward the right until they cut the vertical line *b c*, view (*c*), at *e*, *f*, *g*, and *h*. Then the half-circles *e g* and *f h* are drawn, completing the end view. The semicircles *e g* and *f h* are full lines because both of the curved edges at the ends of the groove can be seen when viewing the block from the right. The end view (*d*) is drawn in the same way as the view (*c*), but by extending projectors to the left. Also, in the view (*d*), the semicircle *f h* is dotted, because this curved edge is not seen when viewing the block from the left side.

13. To draw the view (*e*), Fig. 8, vertical projectors are extended upwards from the points *a*, *b*, *c*, *f*, and *h* in view (*b*), and across them the line *a c* is drawn, locating the points *a*, *b*, *c*, *f*, and *h*, as shown in view (*e*). The distance *a k* is then laid off equal to the thickness of the block, and the horizontal line *k j* is drawn, completing the outline *a k j c*. From the point *b*, the vertical line *b i* is drawn. Then the outlines *a k i b* and *b i j c* represent the faces *a k i b* and *b i j c* of the block, as shown in (*a*). The curved edge of the large end of the groove can be seen when the block is viewed from the top,

and this curved line is shown by the full line $f\,l\,h$ in the top view (*e*). The inner line of the groove is not visible, and it is therefore represented by the dotted line $l\,m$. The point m is located above a at a distance equal to the depth of the groove

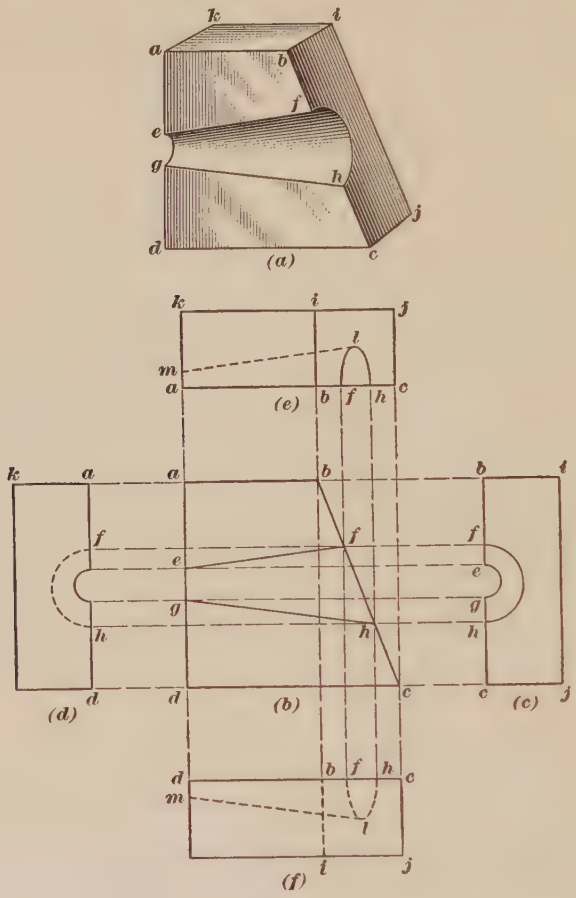


FIG. 8

at the small end. The point l is at a distance above the line $a\,c$ equal to the depth of the groove at the large end; also, it is directly above a point midway between f and h. A smooth curve through the points f, l, and h gives the outline of

the large end of the groove. The bottom view (*f*) is made in the same way as the top view, except that the projectors are drawn downwards; also, as the edge *b i* and the outline of the groove cannot be seen from the bottom, they are shown dotted in the bottom view.

14. From the foregoing example, it should be clear that the use of the projectors is simply to find the correct positions of points and lines in one view from the same points and lines in another view. After the different views are drawn, the projectors are of no value whatever; they are valuable only while the drawing is being made. Therefore, when the tracing of the drawing is being made, the projectors are omitted; consequently, they do not appear on the blueprint. It is an advantage to omit them from the blueprint, for their presence would only add lines that would confuse the drawing and make it harder to read; besides, the projectors are not needed in order to read a blueprint or a drawing properly.

LINES USED ON DRAWINGS

15. Markings on Drawings.—In addition to the several views that are needed to show the form of the object represented, the working drawing contains other lines, marks, figures, and signs, such as dimension lines and figures, lettering showing the names of parts or the title of the drawing, written or printed directions as to the materials to be used or the shop processes to be followed, abbreviations, and so on. The purpose and meaning of these various marks are dealt with more fully later.

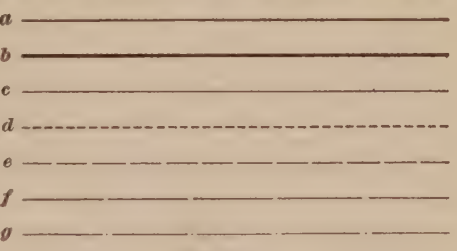


FIG. 9

16. Full Lines.—The several different kinds of lines used on working drawings are shown in Fig. 9, and in order to read working drawings easily and correctly it is necessary

to know the use and meaning of each of these lines. The *medium full line a* is used more than any other kind of line and shows the outlines of the visible parts of an object. The *heavy full line b* is also used to mark the visible outline of an object, but it is employed only in the positions where shading is to be indicated, and for this reason it is frequently called a *shade line*. Shade lines are not used on all working drawings, and when they are not used, the outline is indicated wholly by medium full lines. The *light full line c* is used in cross-sectioning and in making *extension lines*, which are the light lines between which dimension lines are frequently drawn. It is also used on drawings that are to be shade-lined. The pencil lines made in the construction of a drawing are light full lines, also.

17. Dot and Dash Lines.—The *dot line d*, Fig. 9, sometimes called the *short-dash line*, is used to show the outlines and extent of the invisible parts of an object, as, for example, holes or recesses inside a piece of work. The dots are made of the same breadth, or weight, as the line *a*. Dotted lines on drawings that are shade-lined are made of the same weight as the line *c*. The line *e* is the *dash line*. It is used to indicate *projection lines*, or lines that join corresponding points in different views of an object. This line is made of the same weight as the line *c*. Although projection lines are used considerably by the draftsman, they are generally omitted from the finished drawing, so as to avoid confusion of lines. The *long-dash line f* is of the same weight as the line *c* and is used for the dimension lines of drawings. The *dot-and-dash line g* is formed by the regular repetition of a long dash and a dot, and is of the same weight as the line *c*. It is used to indicate center lines and the position of sections taken through an object.

18. Center Lines.—Center lines are reference lines drawn by the draftsman to aid him in making the drawing. They usually, though not always, denote the center of the object and the centers of its parts. The draftsman first draws such center lines as he requires and then constructs the various

views by laying off the dimensions from these lines. Not all the center lines are allowed to remain on the completed drawing in every instance, because they are not necessary and would only make the drawing less clear and less readable. But such center lines as are needed and those which do not confuse the drawing are kept on the finished drawing. They are required particularly where details have been located, but not drawn in full, where measurements are to be laid off from them, and where the work to be built must be laid off from the drawing. In some kinds of patternmaking, for example, the working drawing must be copied directly on the wood or on sheet metal; consequently, the workman in laying out the work must consider the center lines first of all.

SHADING ON DRAWINGS

19. Shading of Holes.—On some mechanical drawings a number of the lines are made much heavier than the others. These heavy lines are *shade lines* and are used to indicate by their positions whether the outline is that of a hole in the work or of a raised part projecting above the surface. For example, Fig. 10 (*a*) shows a perspective view of a rectangular block in which are a round hole *a* and a long slot *b*. A mechan-

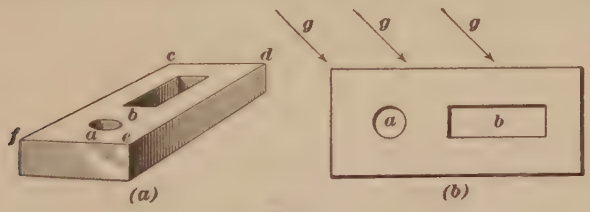


FIG. 10

ical drawing of the block, showing a top view, is given in (*b*), with the proper shade lines. In the case of the round hole, the upper left-hand part of the circle is made heavy; and in the case of the slot, the upper horizontal line and the left-hand vertical line are made heavy. This is the usual way of shading holes. Consequently, if the shade lines forming part of the outline of a piece are located at the upper and left-hand edges,

they indicate that there is a hole or a depression below and to the right of them. The reason for drawing the shade lines in this way may be explained simply. The light by which the piece is seen is supposed to come from above and to the left, and to fall on the top face *c d e f* of the block in the direction of the arrows *g*. The result is that the upper and left-hand edges of the holes *a* and *b* cast shadows in the holes, just below those edges; hence, the shade lines are drawn at those points.

20. Shading of Raised Parts.—A block having a round boss *a* and a long rib *b* on its upper face is shown in perspective in Fig. 11 (*a*), and a plan of the block, properly shaded, is shown in (*b*). In this case, the parts *a* and *b* of the object project above the surface of the work, and the shade lines are at the right and the bottom of the outlines representing these parts in the plan (*b*). Consequently, if the shade lines

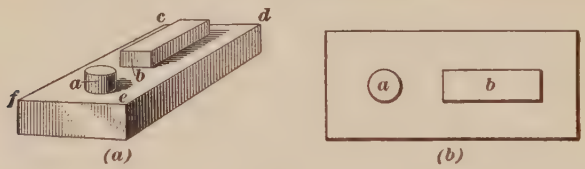


FIG. 11

forming part of the outline of a piece are at the bottom and right-hand edges, they indicate that the part bounded by them is raised above the surface. The right-hand and bottom lines of the drawing are also shade lines, because they represent the edges *c d* and *d e*, which are two of the top edges of the block. They must be shade lines because the surface *c d e f* is raised above the lower surface by an amount equal to the thickness of the block. These latter statements refer also to the block shown in Fig. 10 (*b*).

21. Differences in Use of Lines.—All manufacturing companies do not use the same forms of lines for representing various parts of an object in a drawing. For example, some companies use the medium full line for all the outlines of a part and do not use shade lines at all. Others use the heavy full line, with no shade lines. Again, it is the practice in some

drafting rooms to use the light full line instead of the dot-and-dash line for center lines. Each shop has its own rules in these matters, and the workman should make it his business to become familiar with the usual practice of the company by which he is employed.

SECTIONS

22. Sectional Views.—The various kinds of views considered in preceding articles are external views and they show the appearance of the object as seen from different positions outside it. If the object is not complicated, outside views are sufficient; but if the inside is of peculiar form, or if one part fits into another, it is usually found that external views alone will not be enough. In such a case, one or more *sectional views*, or *sections*, of the object are given also. In making a sectional view, the object is assumed to be cut into

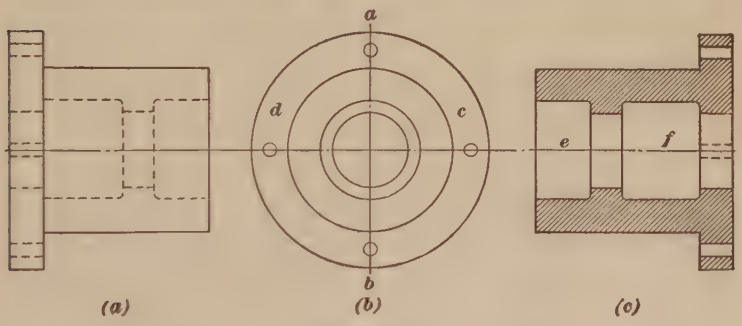


FIG. 12

two parts, the part nearer the observer is supposed to be removed, and the appearance of the remaining part is shown as a section. Thus, while it would be possible to determine from Fig. 12 (*a*) and (*b*) the shape of the object indicated, the sectional view (*c*) makes the drawing much clearer. The object is supposed to be cut in two along the line *a b*, and the right half *c* is assumed to be removed, so that the other half *d* may be viewed on the surface along which it is cut. This view of the half *d* is the section, or sectional view, shown in (*c*).

23. By means of the sectional view, Fig. 12 (*c*), the interior construction of the work is shown clearly. The thickness of the material at various points is plainly indicated, the positions of the recesses *e* and *f* are shown, and all this is done by full lines instead of by the somewhat confusing dotted lines shown in the side view (*a*). One of the most noticeable features of the section (*c*), however, is the series of evenly spaced slanting lines drawn on it. These lines are called *section lines*, or *cross-hatching*, and indicate the surface along which the object is supposed to be cut in making the section. Every sectional view of an object is indicated by cross-hatching or by some similar marking, and when a drawing shows views thus marked, the workman knows at once that such views are sections. Sections are usually taken along center lines, as in the example given, but a section may be taken in any desired direction through an object.

24. Forms of Cross-Hatching.—As many different materials are used in the construction of machinery, it has become the custom to indicate these differences on the drawings by using a particular form of cross-hatching to denote each material. The practice is not the same in all manu-

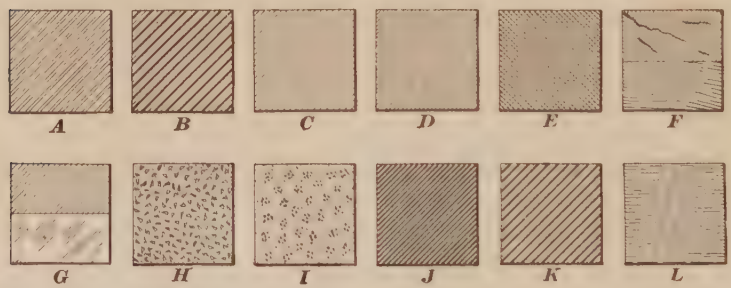


FIG. 13

facturing shops, as each adopts its own standards; in a general way, however, the forms of section lining shown in Fig. 13 represent usual practice. *A* indicates the sectioning used for all forms of steel; *B* shows that used for wrought iron; *C* is the form for cast iron; *D* indicates brass, bronze, and all other alloys containing copper; *E* is the form of section lining

for lead, Babbitt, and soft metal; the upper half of the section *F* is for wood cut across the grain and the lower half for wood cut along the grain; *G* in the upper half, is the sectioning for glass and stone, but when not in section these materials are represented as in the lower half; *H* indicates concrete; *I*, leather; *J*, rubber or wood fiber; *K*, firebrick; and *L*, water. It is becoming the practice in many shops to use the cross-hatching shown in *C* for *all* materials, and to state the kind of material in a note below each piece. Sometimes the materials to be used are given in a *material list*, which is in the form of a table placed either in one corner of the drawing sheet or on a separate sheet. These practices not only lessen the time required for making the drawing, but also diminish the chances of error in using wrong materials.

FIG. 14

25. In case the sectional view is very narrow, so that difficulty would be encountered in distinguishing the style of cross-hatching, the section is usually indicated by blackening it to form a solid black outline, as shown by the examples in Fig. 14. Blackening is done also if the section is to show prominently on the drawing. When two or more sections of this kind meet, a white line is left between them, to show that they are separate, and not in one piece. Solid black sections are most commonly used for sectional views of work composed of plates, angle iron, I beams, channels, and so on.

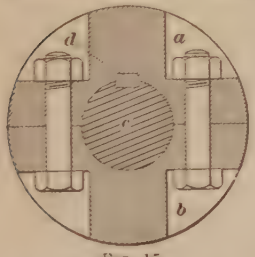


FIG. 15

26. In a sectional view of two or more pieces that are fitted together, the section lines of adjacent pieces are slanted in different directions, so that the difference between the parts may readily be seen. Thus, in Fig. 15 is shown a section of two cast-iron pieces *a* and *b* that are bolted together about a shaft *c* and held from turning by a key, shown in section at *d*.

The section lines of adjacent pieces should be slanted differently, no matter whether the pieces are of the same or of different materials. In Europe it is common practice to indicate sections by various colors, instead of by lines; but this practice is rarely followed in the United States.

27. Classes of Sections.—There are several kinds of sections, and these are named according to the manner or the direction in which the object is assumed to be cut in making the section. A section taken by cutting across a body in the direction of its smallest dimension is called a *cross-section*. If the section is taken in the direction of the greatest length

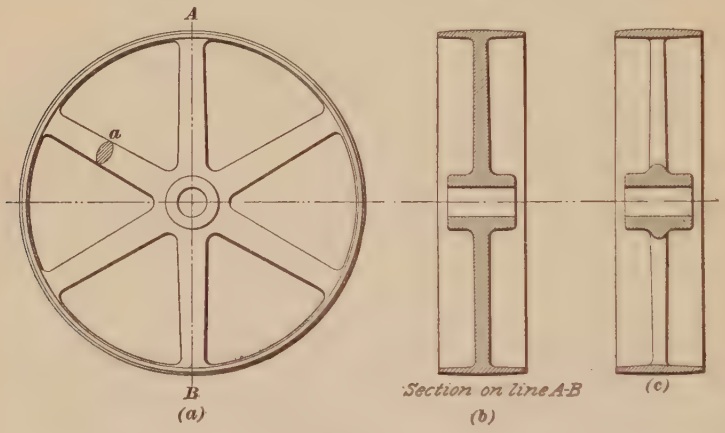


FIG. 16

of the body, it is called a *longitudinal section*. If a cross-section or a longitudinal section is made to show only part of the way through an object, it is then known as a *partial section* or a *half-section*. Sometimes two or more sections of the object are given to show its construction at different points; but if two or more partial sections are combined in one view, they form what is called a *conventional section* or a *conventionalism*.

28. The nature of a conventional section may be illustrated more clearly by reference to Fig. 16, which shows views of a six-armed pulley. The side view (*a*) indicates the center line *A B* along which the sectional view (*b*) is taken. In this

sectional view the arms are shown in longitudinal section, and from a study of this view alone it would be impossible to tell whether the pulley had arms or whether it had a continuous solid web instead. The fact that arms are used, and not a web, may be indicated very clearly by the use of a conventional section (*c*). In this view the rim and the hub of the pulley are shown in section, but an external view of the arms is added. The result is not a true sectional view of the pulley, but a view that is clearer than a true section and is easier to make because it does not require so many short section lines. The cross-section of the arm, shown at *a* in the side view, is the customary way of indicating the shape of the section of the arm.

SCALES AND DIMENSIONS

29. Scales Used on Drawings.—It would be very difficult, and in some cases wholly impossible, to make full-size drawings of all machines or other work to be manufactured. Also, even if such drawings could be made, they would be of so many different sizes that it would be very inconvenient to file them away systematically. For these and other reasons, the usual practice is to make drawings to a reduced scale, that is, to make them some convenient fraction of the full size. Thus, if a piece of work is very large, a drawing of reasonable size may be obtained by making all the dimensions one-eighth of the actual full-size dimensions, or one-fourth, or one-half, as the case may be.

30. The scale to which a drawing is made is usually denoted by stating the number of inches of length on the drawing corresponding to 1 foot of length of the actual piece. For example, if a drawing is made to a scale of 3 inches to the foot, a part of the object that is 1 foot long will be represented on the drawing by a line 3 inches long; or a part 2 feet long will be denoted by a length of 6 inches on the drawing. In other words, as 3 inches is one-fourth of a foot, the drawing will show every part exactly one-fourth of its true size.

The scales to which drawings are made are numerous, the selection of a scale being dependent on such matters as the

size of the drawing sheet used and the clearness and accuracy with which the various parts must be shown. The scale is invariably written or printed on the drawing, in the following style: *Scale 3″ = 1 ft.* The scales commonly used are 6″ = 1 ft., 3″ = 1 ft., $1\frac{1}{2}$″ = 1 ft., and $\frac{3}{4}$″ = 1 ft., but other scales may be employed when special conditions require.

31. Dimensions on Drawings.—The several views on a drawing will show the shape of the object, but in order to indicate its size, dimensions must be marked on the drawing. The dimension figures denote the lengths, diameters, etc. of the various parts in inches, in feet and inches, or in decimal or fractional parts of an inch, according to the size of the work and the accuracy with which it is to be constructed. As shown in Fig. 2, the dimension figures are written at or near the middle points of the dimension lines, which are drawn either across the views of the object or at the sides of the views. An arrowhead is placed at each end of the dimension line, to show just how far the dimension extends. When the part is very short, so that there is no room for a dimension line on the drawing, the dimension figures are written between two arrowheads that point toward each other, as in the case of the $\frac{3}{16}$-inch dimension shown in Fig. 3; and if there is so little space between the arrowheads that the dimension figures cannot be written in, they are placed at one side or the other, on a line with the arrowheads. When the dimension figures are placed on dimension lines at the side or the end of a view, extension lines are drawn outwards from the view and the dimension lines are drawn between the extension lines.

32. The dimensions marked on a working drawing always indicate the actual dimensions of the completed work, no matter what the scale of the drawing may be. Thus, two different draftsmen might make drawings of the same piece of work, one using a scale of 3″ = 1 ft. and the other a scale of $1\frac{1}{2}$″ = 1 ft., but the drawings of both would show exactly the same dimensions for the various parts. If the dimension is 2 feet or smaller, it is usually expressed wholly in inches, as, for example, $\frac{3}{16}$″, $5\frac{1}{8}$″, $11\frac{1}{4}$″, $23\frac{11}{16}$″, the sign ″ being used

to indicate inches. If the dimension is greater than 2 feet, however, it is usually expressed in feet and inches, the sign ′ being used to denote feet; thus, a drawing might show such dimensions as 2′ $3\frac{1}{2}$″, 4′ 6″, etc. Frequently the feet and inches are separated by a short dash, as 3′– $8\frac{1}{4}$,″ to avoid any chance of error. In some shops, all dimensions greater than 1 foot are expressed in feet and inches; whereas, on United States government drawings, dimensions less than 4 feet are expressed in inches. There is no fixed rule in this respect.

ABBREVIATIONS USED ON DRAWINGS

33. Written Abbreviations.—In addition to the dimensions, working drawings frequently contain written or printed abbreviations and directions, and the workman must be able to read these correctly in order to understand the construction and method of making the piece. If he does not understand the meaning of one or more of these written or printed marks, he should consult some one in authority, as the foreman or the superintendent. The most common written abbreviations are *D.*, *Dia.*, *Diam.*, *d.*, *dia.*, and *diam.*, each of which indicates the *diameter* of a part The *radius* of a circular part, which is equal to half of the diameter, is abbreviated *R.*, *Rad.*, *r.*, or *rad.* Thus, if a part is marked $1\frac{1}{2}$″ *dia.*, it is $1\frac{1}{2}$ inches in diameter; and if a curved outline is marked *3′–10″ R.*, it is understood to have a radius of 3 feet 10 inches. If a drawing is made according to the metric system, the dimensions are usually stated in *millimeters*, abbreviated *mm.*; thus, *110 mm.* as a dimension would indicate 110 millimeters. Similarly, the abbreviation *m.* is used for *meters*. Occasionally, the sign ℄ is employed as an abbreviation for *center line*. *Thds.* or *thds.*, preceded by a number, is used to show the number of *threads* per inch; thus, a screw marked *14 Thds.* is to have 14 threads per inch.

34. Various machine-shop operations are often indicated on the working drawing by means of abbreviations and notes. Thus, *f* or *fin.* denotes that the surface marked by that abbreviation is to be finished by machining, grinding, polishing, etc.

Drill indicates that a hole is to be made by drilling. *Bore* or *Bored* is the term used to show that a hole is finished by boring. *Cored* implies that a hole is to be left as it is cast in the foundry. *Black*, which is a term used in connection with forged work, means that the work is to be left as it comes from the smith, without finish. *Tap*, preceded by a number, indicates that the hole is to be tapped with a tool of the size indicated by the number, as, $\frac{5}{8}$″ *Tap*. Sometimes another number is added to signify the number of threads per inch on the tap, as, for example, $\frac{9}{16}$″*–12 Tap;* in this case the tap is understood to be $\frac{9}{16}$ inch in diameter and to have 12 threads per inch. *Planed* calls for finishing by planing. *Mill* for finishing by milling, and *Scraped* for finishing by scraping. A finish by a reamer is marked *Ream* or *Reamed*. *Tool finish* means that the surface, after machining, is not to be finished further. *Shrink Fit*, *Forced Fit*, or *Driving Fit* shows the workman that, in machining the part, he must make the proper allowance for the kind of fit named.

35. Repetition of Details.—When an object has several details, or parts, that are exactly alike, the draftsman saves time by showing only one or two on the drawing and then

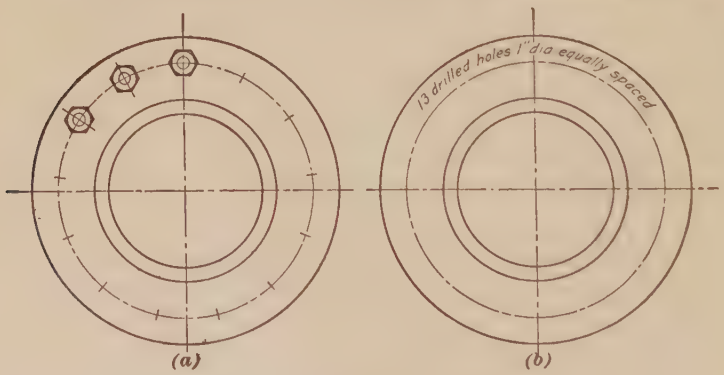


FIG. 17

indicating the positions of the others by marking their center lines; or, he places on the drawing a note stating that certain parts are to be duplicated. These points are clearly illustrated

in Fig. 17, which shows two ways of indicating the positions of the bolt holes in a pipe flange. In view (*a*) are shown three bolts, and the positions of the other bolts are indicated by

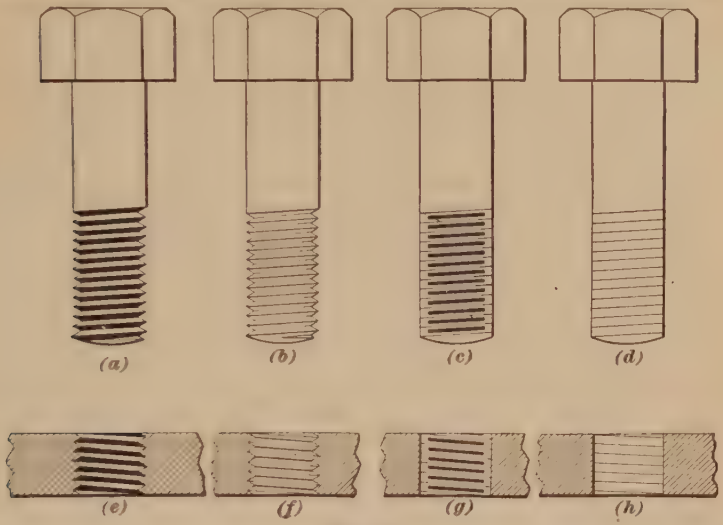


FIG. 18

short lines drawn across the bolt circle. In view (*b*) no bolts are drawn and no positions are indicated, but the note written along the bolt circle explains clearly that thirteen 1-inch holes

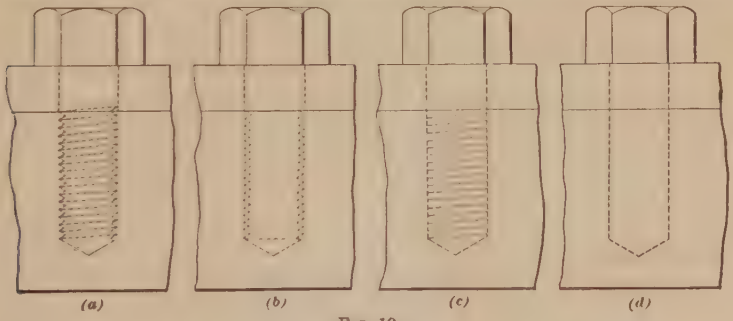


FIG. 19

are to be drilled in the flange, along the bolt circle and at equal distances from one another. These methods of abbreviation are used on drawings of gear-wheels, riveted joints, and

other work having repeated details. In this way the time and expense incurred in making the drawing are lessened, yet the clearness is not sacrificed.

36. Abbreviation of Screw Threads.—Various methods of indicating screw threads are shown in Fig. 18. That in (*a*) shows the thread shaded, and that in (*b*) omits all shading. Because of the time required to draw all the threads in either case, the forms shown in (*a*) and (*b*) are not commonly used on drawings; instead, some conventional method of abbreviation, such as that shown in (*c*) or (*d*), is used. The latter forms are easily and quickly drawn and are quite clear. The views (*e*), (*f*), (*g*), and (*h*) show sections of holes tapped to receive the bolts shown in (*a*), (*b*), (*c*), and (*d*), respectively. The slant of the thread on the drawing of a tapped hole is opposite that on the bolt for that hole.

Fig. 20

When the threaded parts are hidden, so that they must be shown on the drawing by dotted lines, any one of the methods illustrated in Fig. 19 (*a*) to (*d*) may be used. The diameter of the screw should be written on the drawing, and the shape of the thread, the number of threads per inch, and whether the thread is right-hand or left-hand, may be given.

37. A right-hand screw, that is, a screw with a right-hand thread, will advance into a nut or other part when turned in

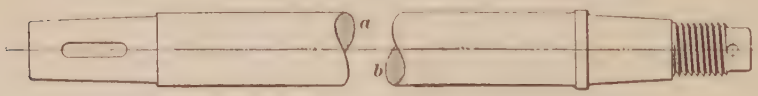


Fig. 21

the direction of the hands of a watch. A left-hand screw will advance when turned in the opposite direction. In Fig. 18 right-hand threads are shown. A view of a left-hand screw and a section of a hole tapped for this screw are shown in Fig. 20.

It may be noticed that the threads slant in the opposite direction from those of right-hand threads. It is not difficult to determine whether a drawing shows a right-hand or a left-hand thread. If it is a drawing of a screw, and the thread slants upwards to the right, the thread is right-hand; and if it slants upwards to the left, it is a left-hand thread. If the drawing is a section of a tapped hole, a right-hand thread is indicated by lines sloping upwards to the left, and a left-hand thread by lines sloping upwards to the right.

38. Breaks.—A break is used to reduce the space occupied by a drawing of a long, slender part, without making use of a small scale. An example of a break is shown in Fig. 21, which represents a cylindrical shaft. A part of the cylindrical portion is assumed to be cut out, and the ends are brought close to each other, the curved lines indicating the break. The surfaces at the break, as at *a* and *b*, are cross-hatched to indicate the material of which the piece is made. Always, when a break is thus used, it is understood that the part cut away is of the same shape and diameter as the parts adjacent to the break. Sometimes, one end of a piece is broken away, instead of the middle.

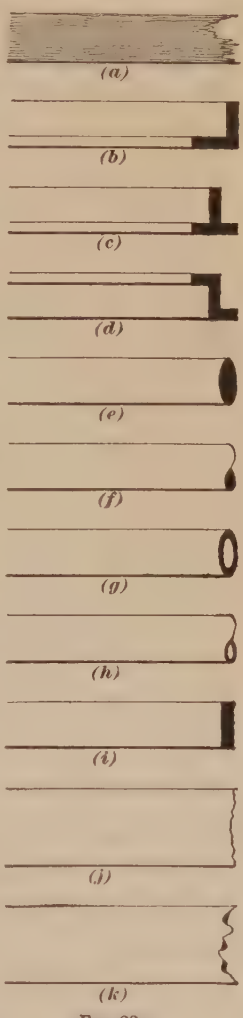


FIG. 22

39. Breaks are indicated in various ways, but usually they show the shape of the cross-section of the object. Some forms of breaks are illustrated in Fig. 22. A break in a wooden piece is shown in (*a*). A bar of angle iron is broken as in (*b*), a bar of **T** iron as in (*c*), and **Z** bars as in (*d*). Cylindrical

objects are sometimes shown broken as in (*e*), but the usual method is that in (*f*). Hollow cylinders, such as pipes, are broken as in (*g*), in some cases, but the more common form is shown in (*h*). Square or rectangular parts have breaks indi-

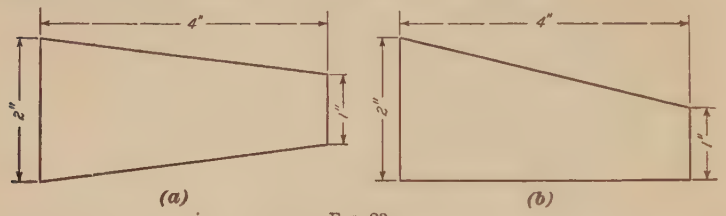


FIG. 23

cated as in (*i*), and plates are shown broken by a wavy line, as in (*j*) or (*k*).

40. Tapers.—The word *taper* means that the piece of work to which it applies grows smaller in cross-section from one point to another. The reduction in size may be made equal on both sides of the piece, as in Fig. 23 (*a*), or it may be made wholly on one side, as in (*b*); each shows a flat wedge.

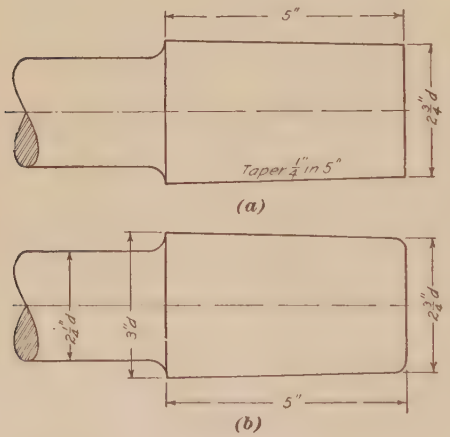


FIG. 24

If a cylindrical piece is turned down so as to diminish in size toward one end, as in Fig. 24, a turned taper is produced. The clearest way of expressing a taper is to mark on the drawing the length of the tapered part and the size at each end of this part, as is done in Figs. 23 and 24 (*b*). Sometimes however, the taper is indicated as in Fig. 24 (*a*); that is, the size at one end and the length of the tapered part are given, and a note indicating the taper is added on the drawing. In this particular

case, the note indicates a taper of $\frac{1}{4}$ inch in 5 inches; that is, in 5 inches of length, the piece changes $\frac{1}{4}$ inch in diameter. As the diameter is $2\frac{3}{4}$ inches at the small end, and the tapered part is 5 inches long, the diameter at the large end is $2\frac{3}{4}+\frac{1}{4}=3$ inches. The taper is sometimes given in inches per foot, as, for example, 1 inch per foot, $\frac{3}{16}$ inch per foot, and so on.

INTERPRETATION OF DRAWINGS

POINTS TO BE OBSERVED

41. Order of Reading Drawings.—The first thing for a workman to do, on receiving a drawing, is to study the views in order to learn the shape of the piece as a whole, after which he should observe the details, or parts, to see their forms and the way in which they are put together. Next, he should read the notes, so as to determine the materials used, the number of pieces required to be made, the operations to be performed, and so on. He may then proceed to lay out the work. In doing this, he will discover whether any necessary dimensions have been omitted and whether any given dimensions are wrong. In either case he should report the matter to some one in authority, and the drawing office should then be notified. No dimensions should be added or changed without consulting the drawing office; also, no workman should begin operations on a piece of work until he fully understands what the drawing requires. Unless special orders are given to him, the workman should never scale a blueprint to obtain a dimension; that is, he should not measure the parts on the blueprint. The wetting and drying necessary in making a blueprint are apt to cause it to shrink, and any measurements taken from it would be incorrect.

42. Sizes Indicated by Dimensions.—In some shops, the dimensions given on the working drawing represent the size that the object is to be when finished; hence, the blacksmith or the patternmaker must make the necessary finishing

allowances. In other shops, the finishing allowance is made by the draftsman and the dimensions given are, then, those of the pattern or forging. If the workman is in doubt about the practice followed, he should find out by inquiry what system is used in the particular shop in which he is employed. In the best modern practice, a note is put on the drawing, calling attention to the fact that the sizes given are those of the finished piece. For example, the note may be *All Finished Sizes*, or some phrase of similar meaning.

43. Accuracy of Dimensions.—The accuracy with which a workman is to work to a given dimension may be stated in a number of different ways. One of these is to indicate the limits of accuracy by smaller figures written above and below the dimension figures, and to the right. Thus, a dimension like $2.25^{+.001''}_{-.001''}$ means that the piece is to be $2\frac{1}{4}$ inches thick, but that it may be $\frac{1}{1000}$ inch large, as indicated by $+.001''$, or $\frac{1}{1000}$ inch small, as indicated by $-.001''$, without being rejected; that is, the thickness may be anything between 2.251 and 2.249 inches.

Sometimes only one limit is given. Thus, $2.25^{-.001''}$ means that the part may be as much as .001 inch under size, but not over 2.25 inches; and $2.25^{+.001''}$ means that the piece may be exact or .001 inch large, but not under size. Another method is to indicate the accuracy by the number of decimal places in the dimension. Thus, a dimension of $2.50''$ indicates that the piece is to be accurate to a hundredth of an inch; $4.375''$ shows that the piece is to be within a thousandth of an inch of the stated size; and $1.1875''$ indicates accuracy to a ten-thousandth. There is no universal system adopted, and the methods given are meant only to illustrate the idea of working to limits.

EXAMPLES OF WORKING DRAWINGS

44. General Drawing.—A general drawing shows the workman the relation between the different parts of a machine and indicates the position occupied by these parts. It is used largely in assembling, or putting together in proper relation,

the different parts that make up the completed machine. For this reason it is frequently called an *assembly drawing*. The general drawing usually has only a few of the principal dimensions on it, and in some cases no dimensions at all are shown. In Fig. 25, for example, is a general drawing of a connecting-rod for a steam engine. It will be seen that the only dimensions given are the diameters and lengths of the bearings and the distance between their centers. Sometimes, however, the general drawing shows also the leading dimensions of the different parts.

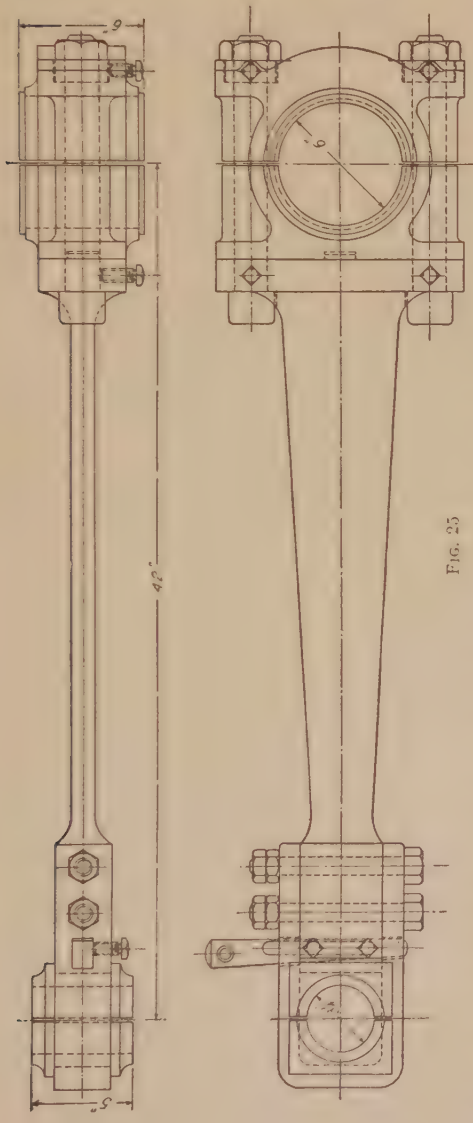


FIG. 25

45. Detail Drawing.—A detail drawing shows the necessary views of each separate part, or detail, of a machine, gives the dimensions, and contains the notes or directions relating to the actual construction of the parts. It may be made so

that the same working drawing may be used by the pattern-maker, the blacksmith, and the machinist; or, if desired, separate working drawings may be made for each, in which case the dimensions, notes, etc. given on the drawing are only those required by the particular workman for whom it is intended. A detail drawing showing the details of the large end of the connecting-rod, Fig. 25, is illustrated in Fig. 26. Views of the box are shown in (*a*) and the Babbitt lining that fits in the box is shown in (*b*). The bolt and the nut shown in (*c*) and (*d*) are used to hold the parts of the box together and to fix them to the rod.

46. The steel casting forming the large end of the connecting-rod, shown in Fig. 26 (*a*), consists of two parts *a* and *b* that are first finished in one piece, and are then cut in two, as at *c*. The amount of metal cut away is $\frac{1}{4}$ inch thick. The center is bored out to a diameter of $6\frac{1}{2}$ inches, and two holes *d* are drilled through with a $1\frac{5}{8}$-inch drill. These holes receive the bolts shown in (*c*). As shown in (*a*), a recess *e*, $1\frac{1}{2}$ inches in diameter and $\frac{3}{8}$ inch deep, is cut in the face of the part *b* that fits against the body of the rod, and the outer ends of the holes *d* are countersunk to a depth of $\frac{15}{16}$ inch, with a diameter of $2\frac{9}{16}$ inches, to receive the projections on the nuts. The nuts are kept from turning by setscrews inserted at *f*, and the holes for the setscrews are tapped with a $\frac{5}{8}$-inch tap. The two small circles marking each of these holes represent the tops and bottoms of the threads. In the end view they are represented by the pairs of dotted lines *g*. The dotted circles *h* represent the finished surfaces *i*, and the dotted circles *j* denote the large countersunk ends of the holes *d*. A boss *k* $\frac{5}{8}$ inch thick and $7\frac{1}{2}$ inches in diameter is formed at each side and is joined to the main part by fillets of $\frac{5}{8}$-inch radius. The surfaces that are to be finished are marked with the symbol *f*.

47. The Babbitt-metal lining for the bearing, shown in Fig. 26 (*b*), is first made in one piece having an overall length of 6 inches and an overall diameter of 7 inches. It is turned down to a diameter of $6\frac{1}{2}$ inches at the middle, thus forming a flange at each end, and the whole is bored out to a

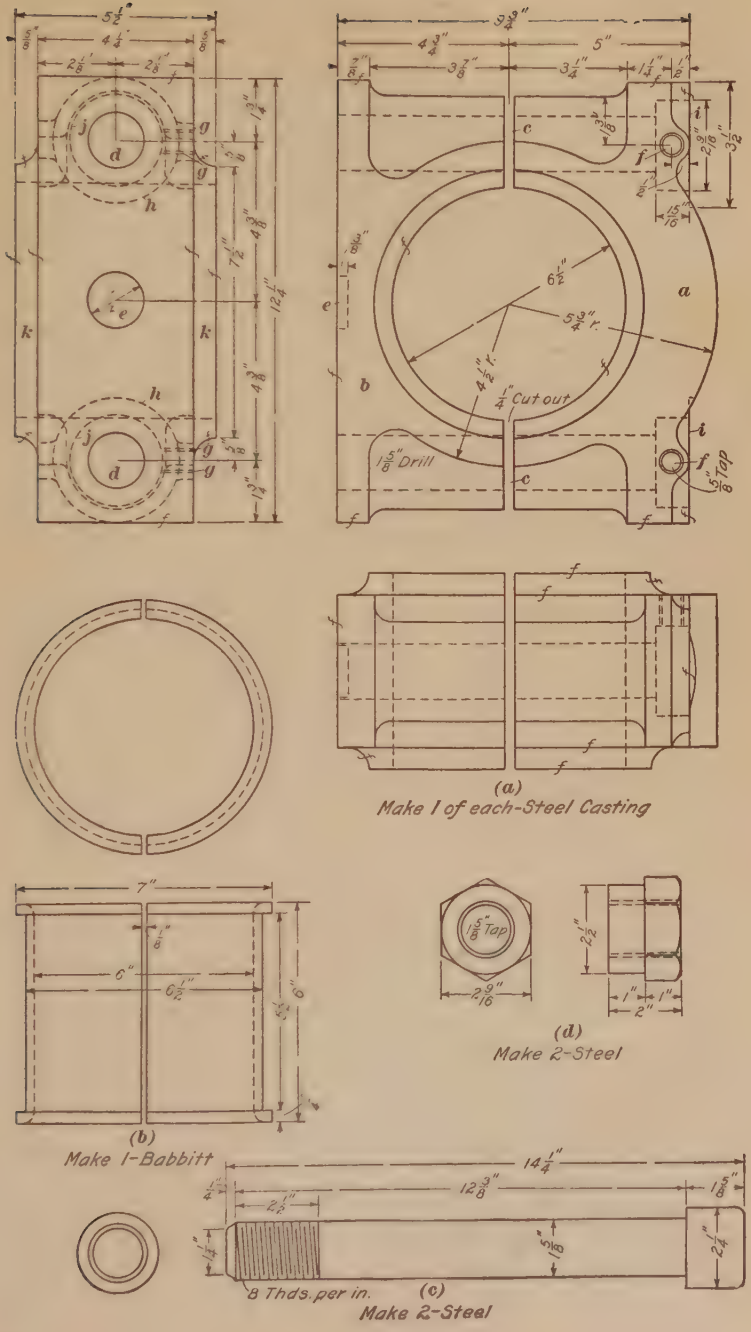

1⅝" Drill
1" Cut out
⅝" Tap
Make 1 of each-Steel Casting
(a)
Make 1-Babbitt
(b)
1⅝" Tap
Make 2-Steel
(d)
8 Thds. per in.
Make 2-Steel
(c)

FIG. 26

diameter of 6 inches inside. A slot $\frac{1}{8}$ inch wide is then cut out, dividing the lining into two parts. This lining fits inside the $6\frac{1}{2}$-inch hole bored in the casting shown in (*a*). The bolt shown in (*c*) has an overall length of $14\frac{1}{4}$ inches, and is threaded at the end for a distance of $2\frac{1}{2}$ inches with 8 threads per inch. The bolt is $1\frac{5}{8}$ inches in diameter and has a round head $1\frac{5}{8}$ inches high and $2\frac{1}{4}$ inches in diameter. In the end view, the two inner circles represent the tops and bottoms of the threads, and the outer circle represents the outside diameter of the head. The nut for the bolt is shown in (*d*). It is a hexagonal

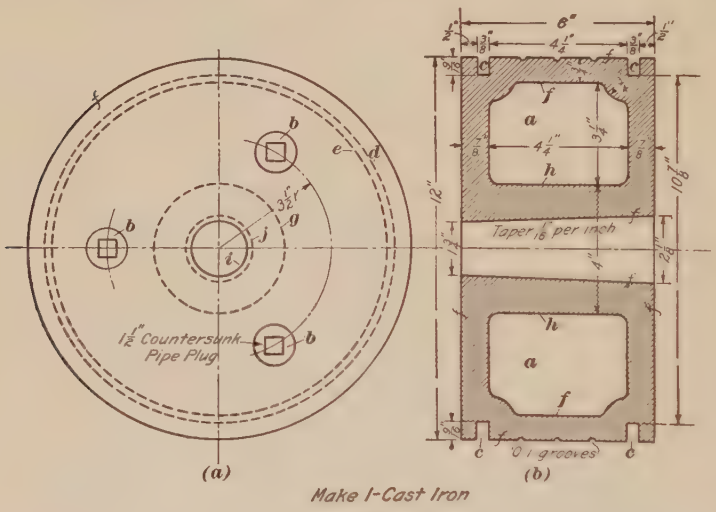


FIG. 27

nut $2\frac{9}{16}$ inches wide across the flats and is tapped with a $1\frac{5}{8}$-inch tap to suit the threaded end of the bolt. The total thickness of the nut is 2 inches, 1 inch of which is formed and chamfered to the hexagonal shape of the nut. The remainder forms an extension 1 inch long and $2\frac{1}{2}$ inches in diameter that fits into the countersunk end of the hole *d* in view (*a*), and against which the end of the setscrew bears. Two of these bolts and nuts are required, and they are to be made of machinery steel.

48. Hollow Piston.—The piston shown in front elevation in Fig. 27 (*a*) and in section in (*b*) has an outside diameter

of 12 inches when finished and is 6 inches thick from front to back. It is finished all over, as indicated by the finish marks *f*; consequently, the patternmaker, in making the pattern for this casting, must allow for the metal cut away in finishing and for the shrinkage of the casting while cooling. The inside of the piston is cored out, as at *a*, and a core must be made for this. It is held in place in the mold by three supports; thus, when the casting is finished, there are in it three holes through which the supports passed. The core is broken up and shaken out through these holes, and they are then tapped and plugged with pipe plugs *b*. The holes are $3\frac{1}{2}$ inches from the center and are equally spaced. The center of the piston is bored with a taper of $\frac{1}{16}$ inch per inch, being $2\frac{1}{8}$ inches in diameter at one end and $1\frac{3}{4}$ inches at the other. The metal is $\frac{7}{8}$ inch thick, and on the circumference are turned two grooves *c* $\frac{3}{8}$ inch wide and $\frac{9}{16}$ inch deep to receive the piston rings. Three oil grooves are also cut in this face. The grooves *c* are $\frac{1}{2}$ inch from the end faces of the piston, but the oil grooves are not definitely located, being cut at about equal distances between the grooves *c*. The dotted circle *d* represents the bottoms of the grooves *c*, and the circle *e* the face *f* of the cored hole. The circle *g* denotes the surface *h* of the cored part, and the circles *i* and *j* represent the ends of the tapered hole.

49. Belt Pulley.—A working drawing of a belt pulley is shown in Fig. 28. In this case, a single view, consisting of a section of the hub and the rim, is sufficient to show the construction, and only a little more than half of the pulley is shown. The face of the pulley is 18 inches wide and is *crowned*, or curved, so that the pulley is greater in diameter at the center of the rim than at the edges. The face is curved to a radius of 80 inches, as marked, and the pulley is 54 inches in diameter at the middle of the face. The dimension lines for these dimensions are not drawn in their full lengths, because the upper half of the pulley is not shown. The dimension line may be broken off and left unfinished, as in the case of the 80-inch radius; or, a double arrowhead may be used to

indicate that the line should extend farther, as in the case of the 54-inch dimension.

50. The outer edges of the rim and the side surfaces of the hub of the pulley, Fig. 28, are faced, as is indicated by the notes marked thereon. The hub has a 5-inch hole bored through it to receive the shaft, and the interior of the hub is cored out to a diameter of $5\frac{1}{2}$ inches and a width of 6 inches. The note *54" Turned* indicates that the pulley is to be 54 inches in diameter when finished by turning. As this is the finished size, the patternmaker understands at once that the pattern must be made larger by $\frac{1}{2}$ inch or so, to allow for the metal removed when turning the face. The number of arms is clearly stated to be six, and it is understood that these are equally spaced. Sections of the arm at points near the hub and near the rim are given to show the shape and dimensions of the arm at these points. Such sections are often placed directly on the arm instead of at the side of it. It has been stated that dimensions of more than 24 inches are usually expressed in feet and inches; but in the case of round work the dimensions are often given wholly in inches, as has been done with the 80-inch and 54-inch dimensions on the drawing.

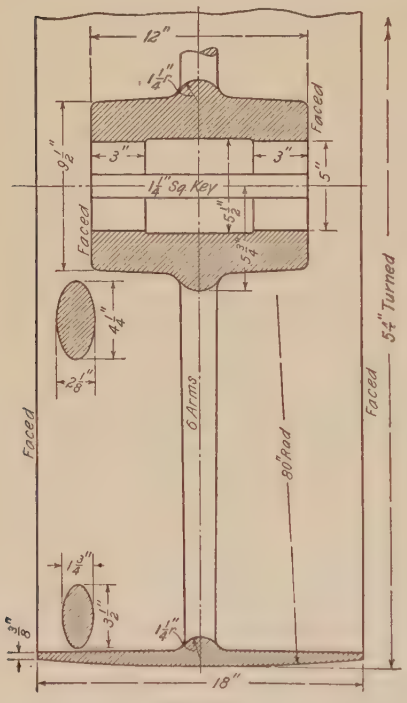


FIG. 28

51. Flange Coupling.—A working drawing of a flange coupling is given in Fig. 29, and each of the two views shows

a half-section, in order to indicate the construction as clearly as possible. The purpose of the coupling is to join two pieces of shafting that come together, end to end, so that they will turn as one piece. To do this, a circular disk is keyed to each piece of shafting and the disks are then bolted together firmly with six $1\frac{3}{4}$-inch bolts, as stated in the note. In the front view, the upper part is shown in section; as the bolt *a* and the keys *c* are shown, it is understood that the section has been taken along the center line *b o* of the side view, and that the part included between *d o* and *o b* is removed. As is customary, the shafts, the keys, and the bolt *a* are not shown in section. The cross-hatching on the coupling to the right and left of the line *e e'* runs in opposite directions, indicating that there are two parts to the coupling and that the line *e e'* shows the joint.

52. In the side view, Fig. 29, are two half views. In the one at the right of the center line *b b'*, the semicircle *f* is shaded so as to show a projection that, by referring to the front view, is seen to be the hub *f*. Furthermore, as the nut on the end of the bolt *a* is shown, it is to be understood that the right-hand half view is a side view drawn in full. In the left half view, nothing is shown in section except the bolts and the shaft. Consequently, the only place where this view could have been taken is along the line *e e'*; for, if the section had been taken at some point on either side of this line, part of the coupling itself would have been sectioned. The side view, by its outline, shows that the coupling is circular; this would also be inferred from the note *Turned all over* placed on the front view, as it is well understood by mechanics that only work of circular cross-section can be finished by turning.

53. The front view, Fig. 29, shows that there is a recess *g* in each half of the coupling, and the shape of the recess is given by the left-hand half of the side view. In the absence of any note or other indication to the contrary, it is to be assumed that the shape of the recess is the same in the other half view. The total depth of the recess is indicated in the front view, and the depth in each half of the coupling is given by the note

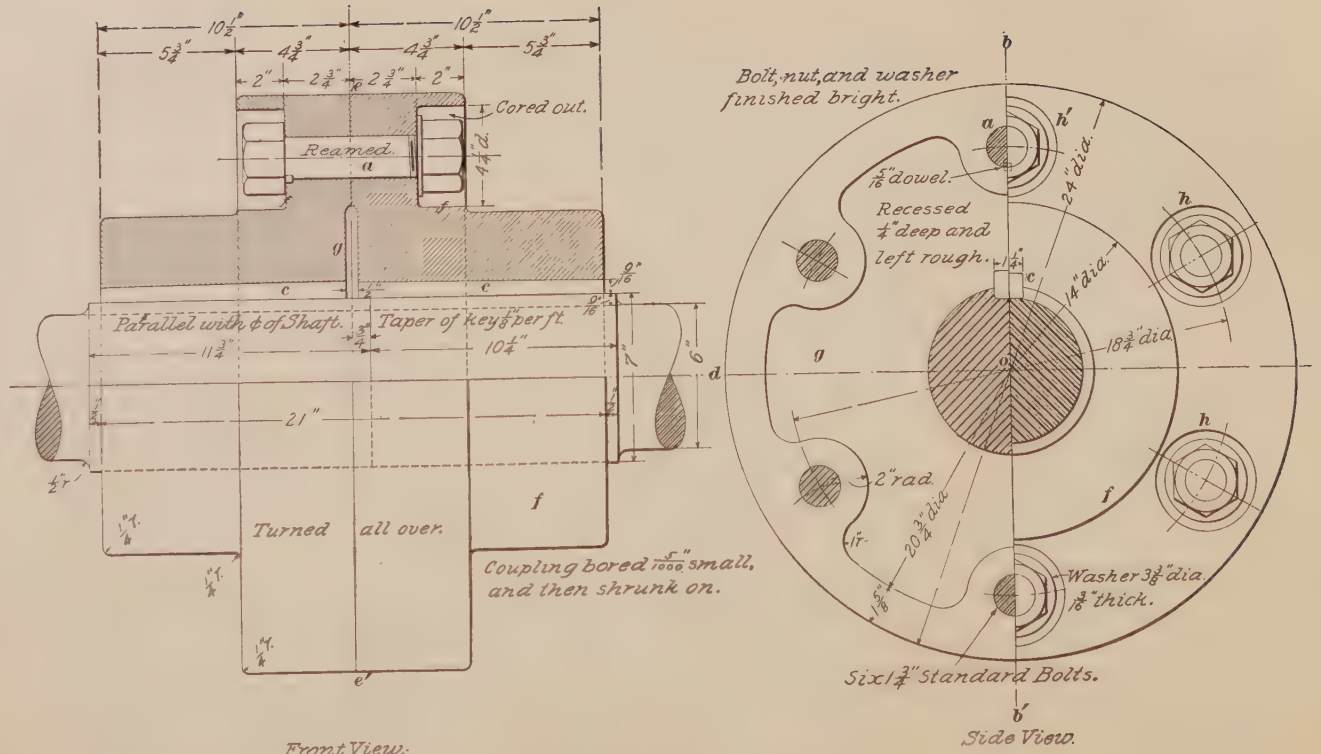

Cored out.
Reamed.
Parallel with ℄ of Shaft.
Taper of key ⅛" per ft.
Turned all over.
Coupling bored $\frac{5}{1000}$" small, and then shrunk on.
Front View.
Bolt, nut, and washer finished bright.
⅛" dowel.
Recessed ¼" deep and left rough.
24" dia.
14" dia.
18¾" dia.
2" rad.
20¾" dia.
Washer 3⅛" dia. ⅜" thick.
Six 1¾" Standard Bolts.
Side View.

FIG. 29

Recessed $\frac{1}{4}$″ deep and left rough, placed on the side view. The fact that there are six bolts is clearly specified by the note, which also gives the size and states that they are to be proportioned in accordance with the United States standard system of screw threads. The hole through which each bolt passes is to be reamed, as stated by the note on the upper half of the front view.

54. The circles *h*, Fig. 29, indicate that the nuts on the ends of the bolts are placed in recesses that have a circular cross-section; if these circles were not shade-lined, it would be necessary to look at the front view to see whether the circles indicate projections or recesses. Neither of the two circles *h* can be seen in the front view, but reference to the side view shows a semicircle *h′* occupying the same position with respect to the center, and, when projected over to the front view, it is seen to be the edge of a recess marked *Cored out*. It will be noticed that the finish mark *f* is placed on the surfaces of the cored recess for the bolt head and nut. This indicates to the machinist that the recess is to be finished and that the finishing should be done by counterboring, which is the most practical way of finishing the recess.

55. As far as the bolts in Fig. 29 are concerned, no bolt circle has been drawn to locate all of them definitely at the same distance from the center. A short arc has, however, been drawn through the center of each bolt; and as the dimension *$1\frac{3}{4}$″ dia.* is placed between two opposite arcs, the workman infers from this that all bolts are located on the same circle, there being no note or other indication to the contrary. The position of the key *c* is fixed by the center line *b b′*, which is seen to pass through two of the coupling bolts. On the front view appears a note *Parallel with ℄ of Shaft*. This note indicates that the keyway is to be cut parallel to the center line of the shaft.

56. Jig for Holding Round Work.—The three views shown in Fig. 30 *(a)* form a general drawing of a jig for holding round pieces. The jig consists of a fixed jaw *a* that is supported on four posts *b* screwed into the corners on the under

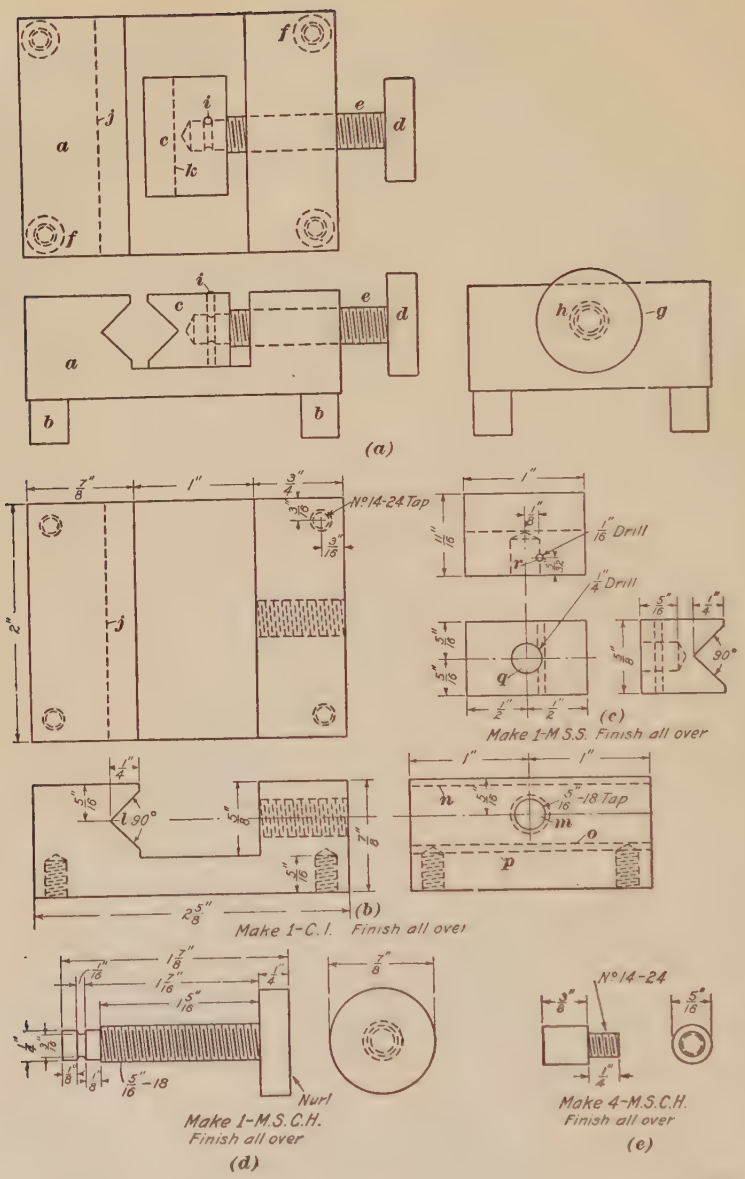

a
b
c
d
e
f
g
h
i
j
k
(a)
No 14-24 Tap
1/16" Drill
1/4" Drill
90°
(c)
Make 1-M.S.S. Finish all over
5/16-18 Tap
(b)
Make 1-C.I. Finish all over
Nurl
5/16-18
(d)
No 14-24
Make 4-M.S.C.H.
Finish all over
(e)

FIG. 30

side, and a jaw *c* that is moved by turning the nurled head *d* of the screw *e*. Each jaw has cut in it a 90° groove, in which the work is held. The dotted circles *f* in the corners of the plan view represent the posts *b*, each of which has three different diameters, namely, the diameter of the body, the diameter over the top of the thread, and the diameter at the bottom of the thread. Similarly, in the end view, the circle *g* represents the nurled head *d* and the dotted circles *h* represent the screw *e*. The end of the screw *e* fits in a drilled hole in the jaw *c* and has a groove cut in it. A pin *i* is driven down through a hole in the jaw and fits in the groove. In this way the screw *e* may turn freely in the jaw, but it cannot pull out. The dotted lines *j* and *k* represent the sharp bottoms of the grooves in the jaws.

57. A detail drawing of the fixed jaw is shown in Fig. 30 (*b*). According to the note, the piece is to be of cast iron and finished all over. The block from which this jaw is formed is $2\frac{5}{8}$ inches long, 2 inches wide, and $\frac{7}{8}$ inch thick. At a distance of $\frac{3}{4}$ inch from one end, a slot 1 inch wide and $\frac{5}{8}$ inch deep is cut across the block, forming the recess in which the work is placed. A right-angled groove *l* is cut in the inner face of the large end of the piece at such a depth that the point of the groove is $\frac{5}{16}$ inch below the top surface. A hole *m* is tapped in the middle of the smaller end $\frac{5}{16}$ inch below the top surface, and a $\frac{5}{16}$-inch tap having 18 threads per inch is used. The four holes for the supporting posts are located so that the center of each is $\frac{3}{16}$ inch from each edge of the bottom of the block, and each hole is $\frac{5}{16}$ inch deep. On the side and end views, the threaded holes for the posts are shown by dotted lines, and the dotted line *j* represents the bottom of the groove. The lines *n* and *o* represent the top and bottom edges of the groove, and the line *p* represents the bottom surface on which the movable jaw slides.

58. A detail drawing of the movable jaw is shown in Fig. 30 (*c*). It is to be made of machinery steel, soft, and finished all over. A block 1 inch long, $1\frac{1}{8}$ inch wide, and $\frac{5}{8}$ inch high is first made, and then along one side is cut a 90° groove

$\frac{1}{4}$ inch deep, so that the bottom of the groove will be $\frac{5}{16}$ inch from the top and bottom faces. In the center of the side opposite the groove is drilled a $\frac{1}{4}$-inch hole q $\frac{5}{16}$ inch deep. On the top face, at a distance of $\frac{1}{8}$ inch to the side of the center line of the hole q and $\frac{5}{32}$ inch from the front face, is located the center of the hole r. At this point, a $\frac{1}{16}$-inch hole is drilled squarely through the block, as shown by the vertical dotted lines. The horizontal dotted line is the bottom of the groove.

The screw, shown in view (*d*), is of machinery steel, case-hardened, and finished all over. The head is $\frac{7}{8}$ inch in diameter and $\frac{1}{4}$ inch thick, and is nurled. The threaded part is $\frac{5}{16}$ inch in diameter, $1\frac{5}{16}$ inches long, and it has 18 threads per inch. At the end, the screw is turned down to a diameter of $\frac{1}{4}$ inch for a length of $\frac{5}{16}$ inch, and a round groove $\frac{1}{32}$ inch deep is cut in the middle of this plain part. The post is shown in view (*e*). Four posts, each of machinery steel, case-hardened, are required. Each post has a body $\frac{3}{8}$ inch long and $\frac{5}{16}$ inch in diameter, with a shank $\frac{1}{4}$ inch long and threaded to fit the holes in the fixed jaw.

59. Tailstock Casting.—Views of the casting forming the body of the tailstock of a lathe are shown in Fig. 31 (*a*) and (*b*). The main center lines *a a*, *b b*, and *c c* pass through the center of the $1\frac{3}{8}$-inch hole *d* bored in the barrel to receive the spindle, and from these lines the principal dimensions are laid off. The body is of irregular shape, being curved at the back, as indicated by the line *c c*, and a recess *f* is formed beneath the middle of the barrel to receive the nut by which the tailstock is clamped to the bed of the lathe. This nut rests on the top of a boss *g* on the lower surface of the recess. Between the back *c c* and the recess *f* there is an opening cored out inside the casting, as is indicated by the dotted line *h h h*. The back surface of the recess *f* is denoted by the dotted line *i i*, and the thickness of metal between the recess and the cored opening is $\frac{7}{16}$ inch, as marked; also, the thickness of the metal at the back is $\frac{7}{16}$ inch. Beneath the boss *g* the metal is cored out as indicated by the line *j j*, and beyond the recess the cored part is carried higher, as shown by the dotted

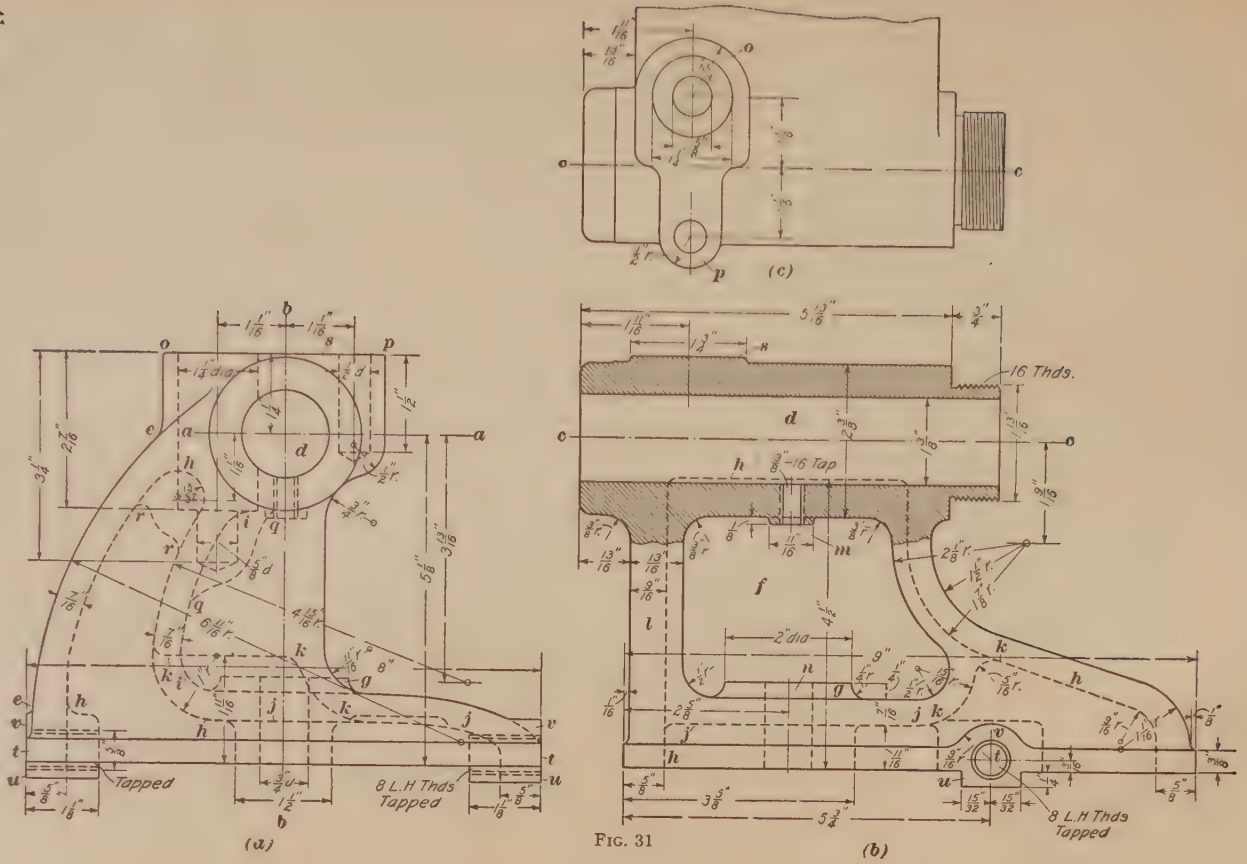


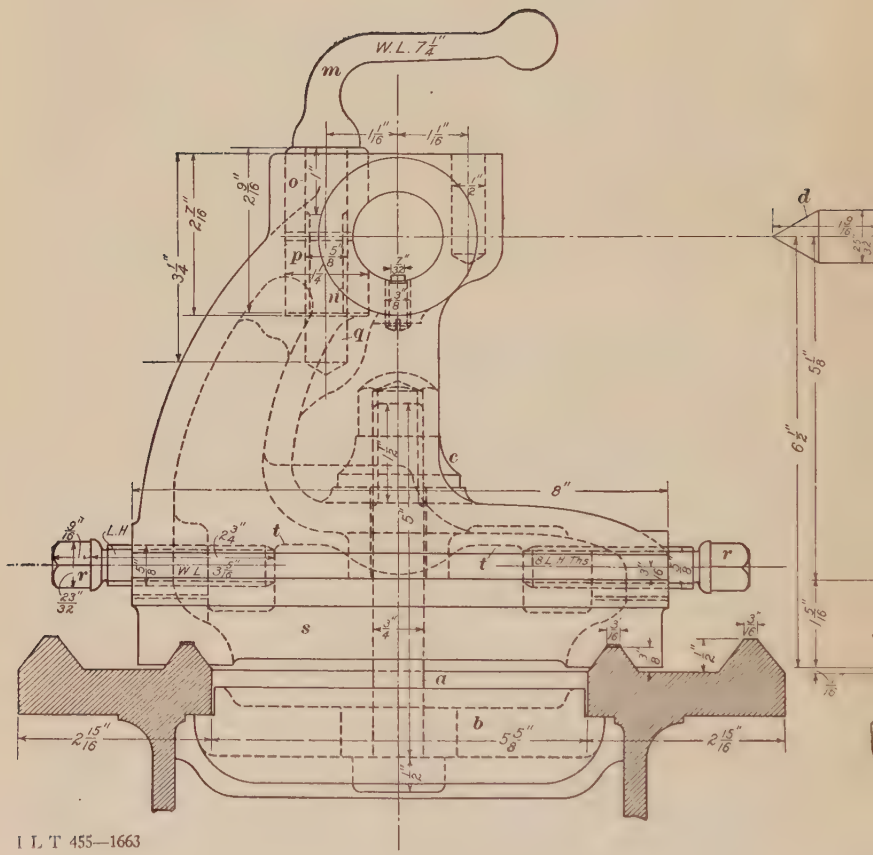
FIG. 31

line *k k*. The barrel is thus supported by a number of metal webs, or walls, varying from $\frac{7}{16}$ to $\frac{5}{8}$ inch in thickness.

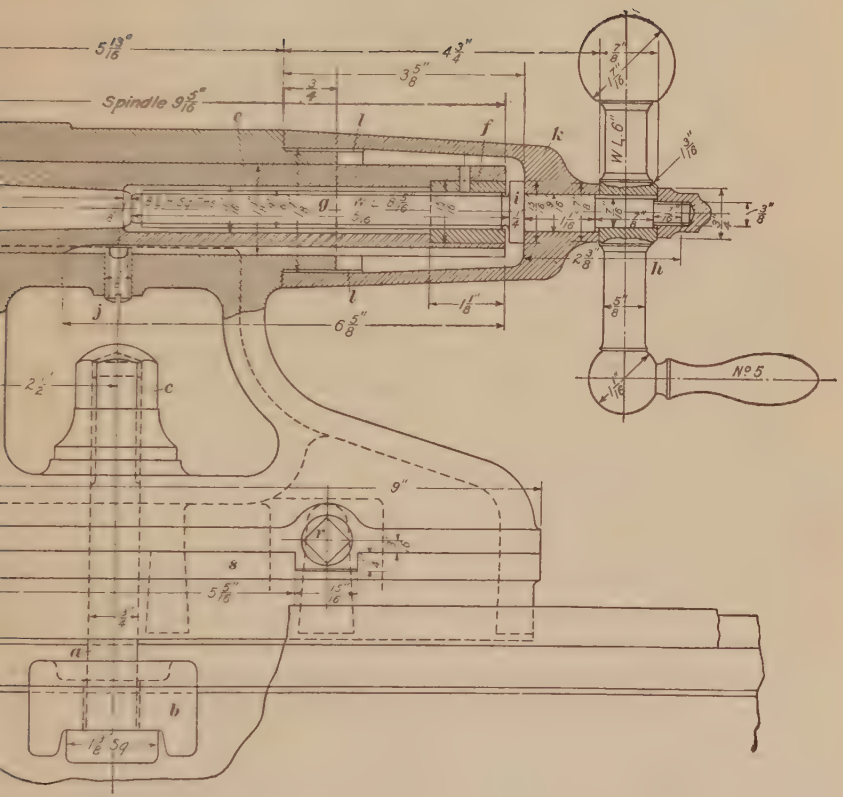
60. The barrel has an overall length of $6\frac{9}{16}$ inches, as shown in Fig. 31 (*b*), and at the end it is turned down for a distance of $\frac{3}{4}$ inch to a diameter of $1\frac{13}{16}$ inches. On this part is cut a screw thread with 16 threads per inch. The opposite end of the barrel overhangs the supporting web *l* by $\frac{13}{16}$ inch. A hole *m* for a setscrew is drilled in the bottom of the barrel, on a line with the center of the hole *n* for the anchor bolt. The hole *m* is threaded with a $\frac{3}{8}$-inch tap having 16 threads per inch, and the threads are indicated by the double lines at each side of the hole. The threads are understood to be United States standard threads, as no definite note is given to state their shape.

A top view, or plan, of the barrel, is shown in (*c*). Two bosses *o* and *p* are formed at opposite sides, on the same center line, at a distance of $1\frac{11}{16}$ inches from the end of the barrel, and the center of each is $1\frac{1}{16}$ inches from the center line *c c*. At the center of the boss *o*, a $\frac{5}{8}$-inch hole is first drilled to a depth of $3\frac{1}{4}$ inches, and this is then counterbored $1\frac{1}{4}$ inches in diameter to a depth of $2\frac{7}{16}$ inches. As these holes would extend through into the cored spaces, metal is added, as shown by the dotted lines *q q* and *r r*, view (*a*), beneath the holes. The boss *p*, view (*c*), has a $\frac{1}{2}$-inch hole drilled at its center to a depth of $1\frac{1}{2}$ inches. The surface *s* of these bosses is faced off so as to be $1\frac{1}{4}$ inches above the center line *c c*.

61. The base of the tailstock casting, Fig. 31, has a length of 9 inches and a width of 8 inches, and projects slightly beyond the unfinished casting all around. The vertical faces of this projecting part of the base are all finished. Two holes *t* are tapped through the base at the sides with 8 left-hand threads per inch. The center is located $5\frac{3}{4}$ inches from the heavy end of the casting, and $\frac{3}{16}$ inch above its lower surface. There is a lug *u* beneath each of the holes *t*, extending $\frac{1}{4}$ inch below the lower surface and $\frac{15}{32}$ inch on either side of the center line through the hole. Each lug is $1\frac{1}{8}$ inches long and is finished on the sides and the bottom. A raised part *v* having a


W.L. 7 1/4"
m
1 1/16"
1 1/16"
o
2 9/16"
2 1/16"
3 1/4"
p
n
q
d
5 5/8"
6 1/2"
c
8"
5"
L.H
t
W.L
r
s
a
b
2 15/16"
5 5/8"
2 15/16"

I L T 455—1663


Spindle
No 5.

radius of $\frac{9}{16}$ inch is formed above each hole *t* to give enough metal around the hole. The radii of the several curved surfaces of the casting, and the centers from which the curves are drawn, are clearly indicated.

62. General Drawing of Tailstock.—A general drawing of a tailstock is shown in Fig. 32. This is the same tailstock casting that is shown in Fig. 31, with the addition of all the parts that are attached to it and a part of the lathe bed on which it is clamped. The anchor bolt *a*, Fig. 32, passes up through a slot in the yoke *b* and is fitted with a capnut *c* that rests on a boss on the casting. When the nut *c* is screwed down, the yoke is drawn up against the bed and the tailstock is firmly held on the V's. The dead center *d* is held in a steel spindle *e* that fits inside the bored barrel of the casting. A nut *f* is pinned to the end of the spindle, and through it passes the screw *g*, to the outer end of which is fixed the handle *h*. The collar *i* and the hub of the handle *h* prevent the screw from moving endwise, and when it is turned by the handle the spindle *e* is moved out of or into the barrel, thus moving the dead center. The spindle *e* has a keyway along its under side, in which fits the flatted end of the setscrew *j*. The spindle is thus prevented from turning, but is free to be moved endwise. The part *k* that carries the screw *g* is threaded inside and is screwed tightly on the threaded end of the barrel, the threads being indicated by the pairs of parallel lines *l*. The thread on the screw *g* is left-hand, so that, when the handle is turned right-handed, the dead center will be moved outwards, away from the tailstock.

63. When the spindle *e*, Fig. 32, has been moved outwards as far as it should go, it may be locked in position by turning the handle *m*. This handle has a threaded stem *n* that passes through the collar *o* and the nut *p* and fits into the drilled hole *q*. Both the collar *o* and the nut *p* are in place when the barrel is bored, and they are cut away at one side to the curve of the spindle. When the handle *m* is turned in the proper direction, the nut *p* is drawn upwards and the collar *o* is forced downwards, and the spindle is clamped firmly between

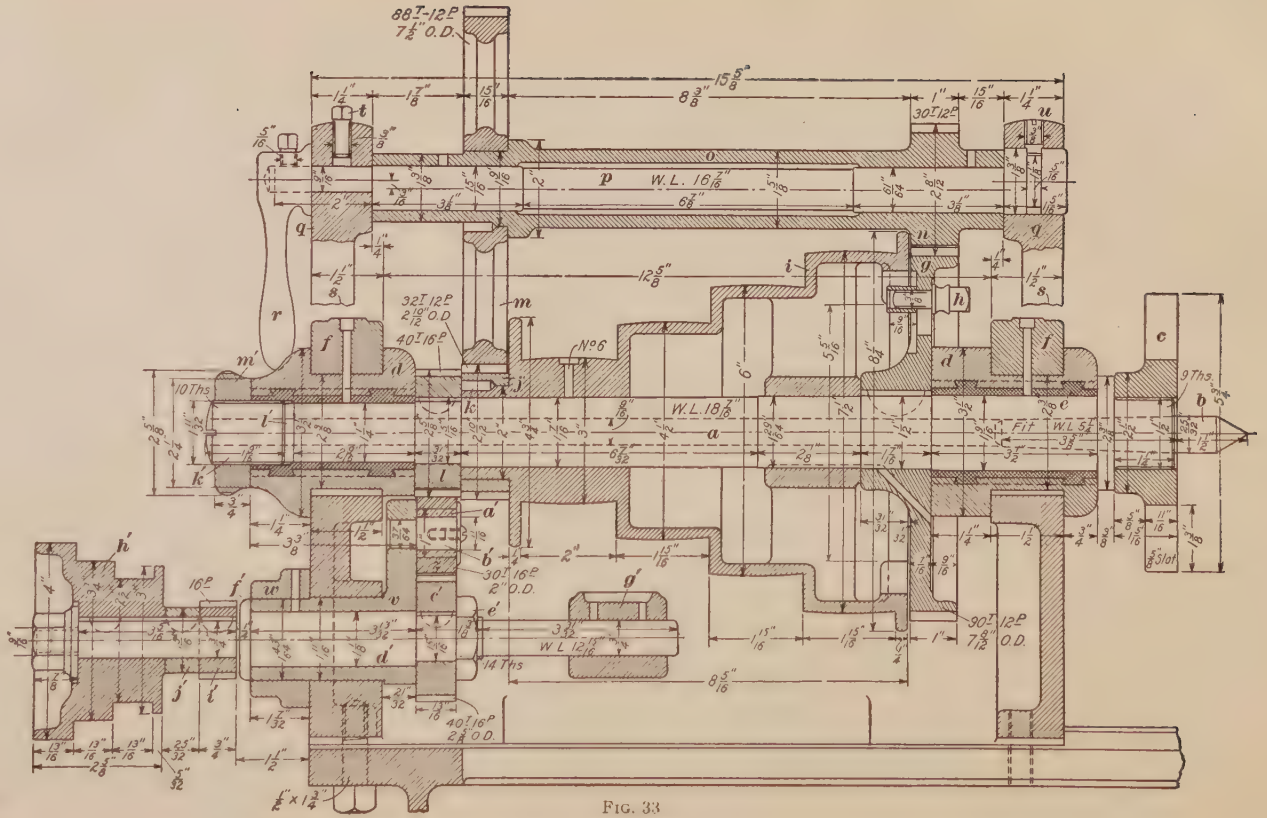

88 T-12 P
7½" O.D.
15⅝"
8⅜"
1¼"
1⅞"
15/16"
1"
13/16"
30 T-12 P
W.L. 16 7/16"
68⅞"
12⅝"
32 T-12 P
2 19/12" O.D.
40 T-16 P
No 6
W.L. 18⅛"
W.L. 5½"
Fit
10 Ths
9 Ths
14 Ths
16 P
30 T-16 P
2" O.D.
40 T-16 P
2¼" O.D.
90 T-12 P
7⅛" O.D.
W.L. 12 13/16"
8 5/16"
1½" x 1¾"
3 Slot

FIG. 33

the two. The adjusting screws *r* furnish a means of changing the position of the dead center sidewise on its base *s*. The base has grooves that fit the ways on the bed, and on its upper side it has two lugs *t* against which the screws *r* bear. The screws *r* are made with 8 left-hand threads per inch. The abbreviation *W. L.* is used frequently on the drawing to indicate the whole length, or overall length, of a part.

64. Lathe Headstock.—A longitudinal section of a headstock for a lathe is shown in Fig. 33, and in Fig. 34 is an end view showing the center lines of several parts, but omitting

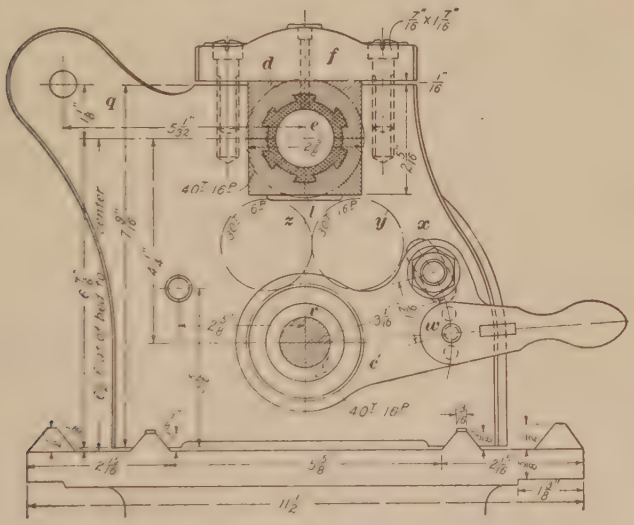


FIG. 34

details. The spindle *a* is of different outside diameters at various points and is drilled with a $\frac{9}{16}$-inch hole except at the inner end, where the hole is tapered to receive the live center *b*. The large end is made $1\frac{1}{2}$ inches in diameter and a screw of 9 threads per inch is cut on it, so that the face plate *c* may be screwed on. The face plate is screwed up until it comes firmly against the collar, which is $\frac{3}{8}$ inch wide. The threaded hole in the face plate is beveled at the ends, to allow the face plate to come solidly against the collar and to give a good

start to the threading tool. Slots $\frac{5}{8}$ inch wide and $1\frac{3}{8}$ inches deep are cut on opposite sides of the center of the plate, to receive the tail of the dog that holds the work. The spindle turns in cast-iron bearing boxes *d* lined with Babbitt metal *e* that is held in by means of dovetailed slots. The boxes are split in halves, as is indicated by the fact that the section lining, or cross-hatching, runs in opposite directions in the upper and lower parts of the boxes. These boxes are fitted into square slots in the frame of the headstock and are held in place by the caps *f*. Oil holes are drilled through the centers of the caps and the upper half of each box to enable oil to be supplied to each bearing.

65. To the spindle *a*, Fig. 33, is keyed the gear *g*, which has 90 teeth of 12 pitch and an outside diameter of $7\frac{8}{12}$ inches, as indicated by the abbreviation *O. D.* This gear has a short slot near the outer rim, in which is a screw *h* that may be moved so as to lock the gear to the cone pulley *i*. The cone pulley is loose on the spindle, and at its smaller end there is fastened to it a small gear *j* by a pin key *k*. This small gear, or pinion, as it is called, has 32 teeth of 12 pitch, and an outside diameter of $2\frac{10}{12}$ inches. Beside it, also keyed to the spindle, is another pinion *l*, made of steel, as shown by the cross-hatching, and having 40 teeth of 16 pitch. When the work is to be rotated rapidly, the screw *h* is set so as to lock the cone pulley and the gear *g*, and the driving belt is put on one of the steps of the cone pulley. The spindle is thus caused to turn at the same rate as the cone pulley and the gear *g*, thus rotating the work by means of the face plate *c*.

66. When the work in the lathe is to be turned slowly, the back gearing is brought into action. It consists of a pair of gears *m* and *n*, Fig. 33, on a sleeve *o* that is loose on a shaft *p* held in brackets *q*. The gear *m* is held to the sleeve by a pin key, but the pinion *n* is in one piece with the sleeve. The shaft *p* is eccentric; that is, its center line does not pass through the centers of the holes in the brackets *q*. As a result, when the handle *r* fixed on the smaller end of the shaft *p* is pushed over away from the spindle, the gears *m* and *n* are

swung backwards, and are drawn out of gear with the wheels *j* and *g*. When the handle is drawn forwards, the gears *m* and *n* are caused to engage with the gears *j* and *g*. When the back gears are thrown into action, the screw *h* is set so that the cone is free from the gear *g*. The cone then turns freely on the spindle, rotating the pinion *j*, which turns the gear *m* on the sleeve *o*. As the pinion *n* must turn with the sleeve *o*, motion is given by it to the gear *g*, which is fast to the spindle, and thus the spindle and the work are rotated; but the speed is much slower than when the cone pulley drives the gear *g* directly.

67. The back gearing in Fig. 33 is shown directly above the spindle *a*, but this is not its actual position. As may be seen in Fig. 34, the brackets *q* supporting the shaft *p* are behind the spindle instead of directly above it. In Fig. 33, therefore, the brackets *q* are not shown joined to the frame of the headstock, but are left with broken lines at *s*, indicating that a conventional section is shown, rather than a true section. The setscrew *t* is screwed down when the shaft *p* is to be held firmly, so as to keep the back gears in action or out of action. A disk of copper or brass between the setscrew and the shaft prevents the latter from being injured. The setscrew *u* is flattened, and its end fits a groove turned in the enlarged end of the shaft *p*. In this way the shaft cannot move endwise, but may turn in its supports *q*. Oil holes are drilled through the sleeve *o* to admit oil to those parts of the shaft *p* on which the sleeve turns.

68. Passing through a bored hole in the outer part of the headstock frame is a bronze sleeve *v*, Figs. 33 and 34, to which is pinned a lever *w* that may be used to turn the sleeve through a small angle, and that may be locked in position by tightening the nut of the clamp bolt in the slot *x*. At the inner end of the sleeve is formed an arm carrying two steel pinions *y* and *z* having 30 teeth each. These two pinions mesh with each other, and either one may be swung into mesh with the gear *l* on the spindle *a* by moving the handle *w*. Each of the pinions *y* and *z* turns on a bronze bushing *a'* fitted on a pin *b'* that

is riveted to the arm of the sleeve *v*. A washer held in place by a screw prevents the pinion from running off. The pinion *z* gears with a small 40-tooth wheel *c'* that is keyed to the shaft *d'* and is held in place by the nut *e'*. This nut, in connection with the collar *f'*, keeps the shaft *d'* from moving endwise. The shaft rotates in the bronze sleeve *v* and the cast-iron bearing *g'* fixed to the headstock casting. At the outer end of the shaft are keyed the cone pulley *h'* and the pinion *i'*, separated by a short sleeve *j'* that is also keyed to the shaft.

69. A plug *k'*, Fig. 33, is threaded over its entire length and is screwed into the end of the box forming the outer bearing of the spindle *a*. A fiber washer or ring *l'* is placed between the plug and the spindle, and the plug is then screwed up against the washer. In this way the fiber washer and the plug take the end thrust of the spindle. The nut *m'* acts as a locknut to keep the plug from turning when it has been correctly set.

The section shown is a conventional one in several respects. The matter of showing the back gearing above the spindle has already been mentioned. The pinion *z* is shown between the pinions *l* and *c'* as if it were on a vertical line between their centers, whereas, Fig. 34 shows that the pinion *z* is not on the vertical center line. The keys shown in the sectional view, Fig. 33, are semicircular in shape and are known as Woodruff keys. In the end view, Fig. 34, none of the gearwheels are shown in full, but they are indicated by circles on which the number of teeth and the pitch are written.

MEASURING INSTRUMENTS

MEASUREMENTS AND MEASURING DEVICES

METHODS OF MEASUREMENT

1. A **measuring instrument** may be defined as any tool, device, appliance, or instrument that can be used to measure or compare a linear, angular, superficial, or cubic dimension, a manifestation of force, physical property, or temperature, with some established unit of measurement. A **gauge,** in its broadest sense, is any kind of measuring instrument; however, among mechanics it is understood to be any reasonably unchangeable device or appliance that is used to establish or define some particular linear or angular dimension, but that cannot be used to measure, in principal or secondary units, any other dimension.

2. **Secondary units** are integral parts or multiples of the principal units. For example, the yard is a principal unit of linear measurement, and the foot and the inch are secondary units, because they are integral parts of the yard; also, the mile is a secondary unit, because it is a multiple of the yard. The minute and the second are secondary units of angular measurement, as they are integral parts of the degree, which is the principal unit. The difference between a measuring instrument and a gauge, then, is that the former measures a dimension by comparing it with a unit, whereas the latter defines a particular unit or a part of a unit.

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3. Kinds of Measurements.—Measurements made by comparing the coincidence or agreement of lines with the aid of a microscope, a simple magnifying glass, or the naked eye, are called **line measurements.** An example of a line measurement is illustrated in Fig. 1, in which the calipers *a* are set to a distance of $2\frac{1}{2}$ inches on the scale *b* by noting when the line *c* of the scale coincides with the inner edge of the leg *d* of the calipers. Measurements made by comparing lengths by means of instruments that are brought in contact with the opposite ends or faces of the pieces to be compared are called **end measurements.** A measurement of this kind is shown in Fig. 2, in which the diameter of the piece *a* is determined when the inner surfaces of the jaws of the gauge *b* just touch the piece *a*. Thus, a line measurement is made by eye, and an end measurement by touch.

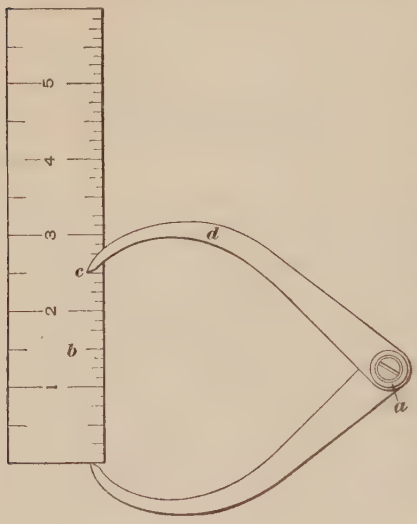


FIG. 1

4. When measurements are made to determine an angle, or the amount of opening between two lines that meet or cross, they are called **angular measurements.** Such measurements are made by comparison of the coincidence of lines, by end measurements, or by a combination of these two methods. In many cases the measurements made by a mechanic are such a combination. Thus, the setting of a pair of calipers to a given dimension by the use of a steel rule is a line measurement, whereas, the measuring of a piece of work by the

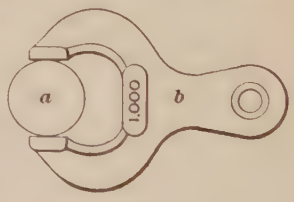


FIG. 2

calipers thus set is an example of end measurement. In using a bevel protractor, the mechanic sets it to the given angle by line measurement; but when he brings the protractor in contact with the work so as to compare the angle of the work, he makes an end measurement. The angular measurement thus becomes a combined line and end measurement.

STANDARDS OF MEASUREMENT

5. English Standard.—In the United States of America, in Great Britain, and in most of the British colonies, the principal unit of length is the **imperial yard,** which is the distance between two marks near the opposite ends of a bronze bar kept within the walls of the Houses of Parliament, London. This original bar is known as Bronze No. 1. Several copies of this bar were made at various times, and in 1856 two copies were delivered to the United States Government.

6. American Standard.—In 1866, Congress passed a law declaring a bar in the possession of the Government, defining a length of 1 meter, to be the legal standard. Thus, the only standard of length recognized by law in the United States is the meter, which is the unit of length in the French system of measurement, and which is equivalent to a distance of 39.37 inches. This metric bar is now the basic or ultimate standard of length in the United States. By the act of 1866, the legal yard was established as $\frac{3600}{3937}$ of the length of the meter marked on the metric bar. This yard corresponds to the yard denoted on the two bars presented to the United States by the British Government. Although these two bars were never declared the legal standard, they are used as standard bars whenever great precision of measurement is required.

7. Working copies of the standard bars in the possession of the United States Government have been constructed by private firms engaged in the manufacture of measuring instruments and gauges. These copies have been carefully compared with the standard bars, and form the working standards of

reference of the manufacturers, but the standard bars in the possession of the government form the ultimate standard of reference.

8. Angular Standard.—So far as measurements of angular dimensions are concerned, no ultimate standard of reference is required, as the degree, which is the principal unit of angular measurement, can always be found by dividing a circle into 360 equal parts.

9. Units of Measurement.—For ordinary work, the English system of measures is in general use, but for scientific purposes the metric system is preferred. The latter system is also frequently employed in connection with various forms of engineering work, and for this reason the corresponding values of the units in the English and metric systems should be learned. The meter has a length of 39.37 inches; hence, the following *conversion factors* may be used to change the units of one system into the units of the other system:

Metric to English		English to Metric	
1 meter (m.)	= 39.37 inches	1 foot	= .3048 meter
1 meter	= 3.28 feet	1 inch	= .0254 meter
1 centimeter (cm.)	= .3937 inch	1 inch	= 2.54 centimeters
1 millimeter (mm.)	= .03937 inch	1 inch	= 25.4 millimeters

Example 1.—Reduce 1.5 meters to inches.

Solution.—As 1 m. = 39.37 in., a length of 1.5 m. is equal to $1.5 \times 39.37 = 59.055$ in. Ans.

Example 2.—How many inches are there in a length of 20 centimeters?

Solution.—As 1 cm. = .3937 in., a length of 20 cm. is equal to $20 \times .3937 = 7.874$ in. Ans.

Example 3.—Convert $3\frac{1}{2}$ inches to centimeters.

Solution.—As 1 in. = 2.54 cm., $3\frac{1}{2}$ in. is equal to $3\frac{1}{2} \times 2.54 = 8.89$ cm. Ans.

Example 4.—How many millimeters are there in a length of $7\frac{1}{2}$ inches?

Solution.—There are 25.4 mm. in 1 in.; hence, $7\frac{1}{2}$ in. is equal to $7\frac{1}{2} \times 25.4 = 190.5$ mm. Ans.

Example 5.—A certain piece of work is 125 millimeters long. What is its length in inches?

Solution.—As 1 mm. = .03937 in., a length of 125 mm. is equal to $125 \times .03937 = 4.92$ in. Ans.

FORMS OF MEASURING INSTRUMENTS

INSTRUMENTS FOR LINEAR MEASUREMENT

10. Two-Foot Rule.—The most familiar measuring instrument for the comparison of linear dimensions is the two-foot rule, shown in Fig. 3 (*a*), which is usually made up of four leaves hinged together to allow it to be folded so as to be carried easily. For the sake of convenience, the edges on both sides are usually graduated with different kinds of subdivisions; frequently, two or more kinds of subdivisions appear on the same edge. Thus, the rule being 24 inches long, one edge may be divided into 24 inches, and each inch subdivided into halves, quarters, and eighths. The opposite edge may have 12 inches

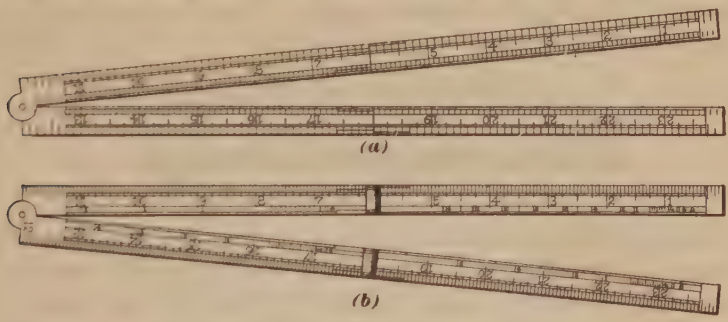


FIG. 3

subdivided into tenths, and the remaining 12 inches subdivided into twelfths, as shown. On the opposite side, the rule will often be found to have one edge divided into 24 inches, subdivided into halves, quarters, eighths, and sixteenths. The fourth edge often carries graduations marked $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, etc., as shown in (*b*). These numbers refer to *reduced scales*; thus, on the part marked $\frac{1}{2}$, an actual length of $\frac{1}{2}$ inch represents a length of 1 foot; on the part marked $\frac{3}{4}$, an actual length of $\frac{3}{4}$ inch represents 1 foot; and so on.

11. Two-foot rules are usually made of boxwood; the most expensive ones are made of ivory. Divisions smaller than

$\frac{1}{16}$ inch are rarely marked on them, for they become so soiled in use that fine divisions could not be read. When divided into sixteenths, the smallest fraction of an inch that can be directly measured is $\frac{1}{16}$, but with a little practice the middle point between the sixteenth-inch marks can be located with a fair degree of accuracy, thus making it possible to measure distances as small as $\frac{1}{32}$ inch. Usually, each inch graduation is marked by a number that represents its distance in inches from the right-hand end; that is, the numbers increase from right to left. The numbers increase from right to left because the two-foot rule is mostly used in such a manner that its right-hand end forms a stop from which the required dimension is transferred by a lead-pencil mark or by scribing to the work. The two-foot rule is well adapted for rough work, where accuracy of measurement is not absolutely necessary.

12. Engineer's Pocket Rule.—Very frequently it is convenient to have a rule more than 2 feet long. Mea-

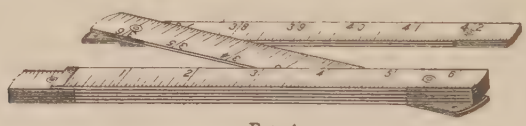



FIG. 4

surements of more than 2 feet can be made with tapes, but when a tape is used both ends of it must be held; whereas, on account of the greater stiffness of the rule, approximate measurements can be made when only one end is supported. On this account, the form of rule shown in Fig. 4 has been brought out. It consists of a number of short wooden pieces joined by pins and provided with special spring joints that keep the rule in a straight line when open. The ends are provided with brass tips. This rule is made in lengths of from 2 feet to 8 feet, and is divided into inches and sixteenths, or into millimeters, if in the metric system.

13. Steel Tapes.—In measuring distances greater than a few feet, steel tapes are very convenient. They are thin bands of steel made in lengths varying from 2 to 100 feet for shop use. Instead of being cut in as in other rules, the graduations on a

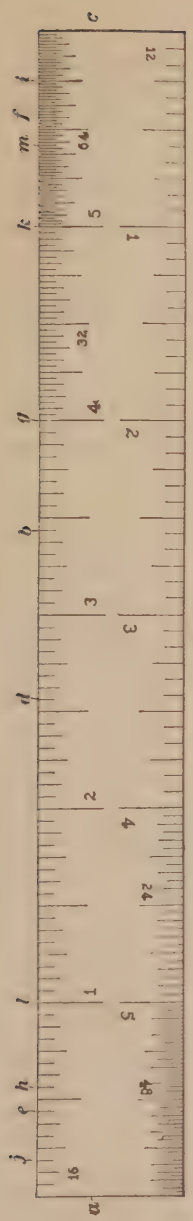


FIG. 5

steel tape are raised. The divisions are not very fine; hence, tapes are suitable only for approximate measurements.

14. Standard Steel Rule.—For the use of machinists and for more accurate measurements in general, so-called steel rules are used. In the better class of these instruments, all graduations are cut in a dividing machine. Standard steel rules bought in the open market are always graduated on both edges of each side, and a large choice of different kinds of graduation is offered by the makers. In Fig. 5 are shown the graduations of one side of a six-inch standard steel rule having several kinds of graduation along each edge. For convenience, and also for the purpose of an extensive range, the different kinds of graduation on each edge are usually made multiples of one another; thus, on one edge are given divisions of the inch into 12, 24, and 48 parts, and on the other edge into 16, 32, and 64 parts. The figures denoting inches almost invariably increase from left to right, or in a direction opposite to that in which they are given on a two-foot rule.

15. Setting Calipers on Steel Rule. In the use of the steel rule, several cases may arise, each of which requires a different method of procedure. Suppose, for example, that a pair of calipers is to be set to a measurement of $3\frac{7}{16}$ inches by the use of the rule shown in Fig. 5. One leg of the calipers is placed against the left end *a* of the rule, in line with the series of graduations marked by the number 16 in small figures. The calipers are then opened, by moving the other

leg to the right along the rule, until this leg comes in line with the mark *b*, which is the seventh mark beyond the 3-inch mark, counting from the left end. The calipers are then set to a measurement of $3\frac{7}{16}$ inches. If it is found more convenient, the measurement may be made from the right end *c* of the rule. In this case, one leg of the calipers is placed against the right end of the rule, and is opened by drawing the other leg toward the left until the mark *d* is reached. This mark *d* is $3\frac{7}{16}$ inches from the right end, for, in opening the calipers to this point, the movable leg passes over 3 whole inch divisions, and 7 of the small divisions denoting $\frac{1}{16}$ inch each, or a total distance of $3\frac{7}{16}$ inches.

16. It will be observed that in the second case no attention was paid to the figures denoting the inch divisions. As these figures become smaller in value toward the left, the operation that was performed was distinctly a case of mechanical subtraction; that is, $3\frac{7}{16}$ inches was subtracted from the total length of the scale, which is 6 inches. Then, the line denoting a distance of $3\frac{7}{16}$ inches from the right end is $6-3\frac{7}{16}=2\frac{9}{16}$ inches from the left end. Thus, the subtraction may be performed arithmetically, in order to find the position of a line denoting a given distance from the right end, or it may be performed mechanically. In the latter case, the actual subtraction is saved; there is also less danger of making an error.

17. As a further illustration, suppose that the calipers are to be set to a measurement of $5\frac{9}{16}$ inches on the steel rule, Fig. 5. This may easily be done by working from the right end *c* and counting off to the left 5 whole inch divisions and 9 sixteenth divisions to the mark *e*. But if the left end of the rule is used, the movable leg of the calipers will finally be brought to some point between the line 5 and the end *c* of the rule. This last inch division at the right is subdivided into sixty-fourths of an inch, and $\frac{9}{16}$ inch $=\frac{36}{64}$ inch. Therefore, with one leg of the calipers placed against the end *a* of the rule, the other leg is moved to the right over 5 whole inch divisions, and then over 36 of the sixty-fourth divisions, to the mark *f*. The calipers are then properly set to $5\frac{9}{16}$ inches.

18. Setting Dividers on Steel Rule.—When setting a pair of dividers on a rule, the greatest accuracy can be obtained by placing them so that their points coincide with division lines that are the required distance apart. Thus, suppose that dividers are to be set to $3\frac{7}{16}$ inches on the rule shown in Fig. 5. Then, if one point is placed in the division mark g of the fourth inch, it is necessary to count to the left 3 whole inches, and 7 sixteenth divisions, to the mark h, and to adjust the other point until it just drops fairly into the mark h. Sometimes it is more convenient to work to both right and left of a whole inch mark. Thus, it is possible to start at the 1-inch mark, and count 7 sixteenth divisions to the left of it, to the mark h, and 3 whole inches to the right of it, to the mark g, to get the positions of the division marks denoting a distance of $3\frac{7}{16}$ inches.

19. If a pair of dividers is to be set to $5\frac{9}{16}$ inches on the rule, Fig. 5, it is not possible to put one point of the dividers in one of the whole inch marks, as the greatest measurement that can then be obtained is only 5 inches, or less than the required dimension. Neither is it possible to use the first half-inch mark, either on the right end or on the left end, as the largest measurement that may then be obtained is only $6-\frac{1}{2}=5\frac{1}{2}$ inches, or less than the required dimension. But it is possible to find the location of a graduation mark from which to start the measurement by choosing a graduation that is nearer the end of the rule than the difference between the length of the rule and the given dimension. The difference is $6-5\frac{9}{16}=\frac{7}{16}$ inch. Choosing the graduation mark i representing the first quarter-inch from the right end, one point of the dividers is placed in it. Now, considering this line as the starting point of the graduations, and disregarding the whole-inch marks entirely, 5 whole inches and then 9 of the sixteenth divisions are counted off, locating the division mark j. The other point of the dividers is then brought fairly into the division line j, which in this case is $6-(\frac{1}{4}+5\frac{9}{16})=\frac{3}{16}$ inch from the end of the rule, and the dividers are then correctly set to $5\frac{9}{16}$ inches.

20. When a measurement is to be made that has a fraction expressed in multiples of the smallest number of divisions

given on the rule, it is usually most convenient to work to both right and left of the mark that defines the beginning of the graduations representing the denominator of the given fraction. For instance, referring again to Fig. 5, let it be required to find the division lines that define $4\frac{27}{64}$ inches. As the divisions representing sixty-fourths commence at the 5-inch mark k, it is necessary to count off 4 inches to the left of this mark, locating the mark l, and then to count off 27 sixty-fourth divisions to the right of it, to the mark m; the distance $l\,m$ is then the required length, or $4\frac{27}{64}$ inches.

FIG. 6

21. Shrink Rule.—All metals shrink somewhat in cooling; allowance must therefore be made in forming the pattern or the mold, in order that the casting may be of the correct dimensions. The average amount of shrinkage is $\frac{1}{8}$ inch per foot for cast iron; that is, if the mold for a rectangular bar is $12\frac{1}{8}$ inches long, the casting will be about 12 inches long. To make a pattern with the aid of an ordinary rule would require a calculation for each separate dimension, in order to obtain the proper shrink allowance; hence, the patternmaker or the molder uses a special shrink rule, in which $12\frac{1}{8}$ inches is taken as 1 foot. This lengthened foot is subdivided into 12 equal parts, called inches, and each inch is subdivided into sixteenths. By the use of this rule the proper shrink allowance for an iron casting is then made.

22. Shrink rules are made of steel or of boxwood; they can be obtained for cast iron, brass, and other metals. In shrink rules intended for cast iron, $12\frac{1}{8}$ inches represents a length of 1 foot. Those intended for brass castings have a shrink allowance of $\frac{3}{16}$ inch per foot; that is, $12\frac{3}{16}$ inches represents 1 foot. Many shrink rules, for convenience, have a standard graduation on one edge and a shrink graduation on the other edge. Thus, the shrink rule illustrated in Fig. 6 has the standard graduation on

one edge; the opposite edge has a length of $12\frac{1}{8}$ inches, divided into 12 parts subdivided into 16 parts each.

23. Graduation of Shrink Rule.—Where patterns are made for castings poured from special alloys, it is often advantageous to have a shrink rule that exactly corresponds with the amount of shrink required for the alloy in use. Any such special rule may be made by the method illustrated in Fig. 7. A standard steel rule is laid down, as shown at *a b*. The amount of shrink per foot of length is laid off as shown by *b c*. Then, with *a* as a center, the arc *c d* is drawn with a pair of dividers. The point *d* at which the arc intersects the line *b d*, *b d* being square with *a b*, represents one end of the required shrink rule.

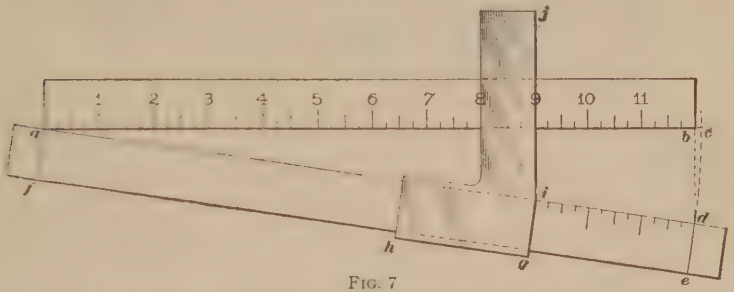


FIG. 7

The rule is usually made from a piece of hardwood. The stock is planed to the same thickness as the steel rule by which it is to be graduated.

24. The stock should be left somewhat longer than the required rule, and placed with one edge as shown at *a d*, Fig. 7. A special templet or square for graduating is necessary. This can be made of a piece of sheet brass or steel, or it may be made of wood. The general form is shown in the illustration. The edge *g h* is bent down so that it will be guided by the edge *e f* of the required rule. The edges *a d* and *e f* must be parallel. The side *i g* is perpendicular to *e f*, and *i j* is perpendicular to *a b*. By sliding the special graduating piece along the edge *e f*, the edge *i j* may be brought in line with any graduation on the standard rule, and corresponding lines may be drawn on the special rule along the edge *i g* by using a knife or any

suitable scribing tool. Care must be taken to hold the scribing tool in the same position while drawing each line. Shrink rules made by this process are accurate enough for any ordinary shop work.

25. Key-Seat Rule.—A useful tool for key-seat work is the key-seat rule shown in Fig. 8. It consists of two straightedges *c* and *d* clamped or formed together so as to make a box square. In the form shown, a graduated scale *c* is clamped to

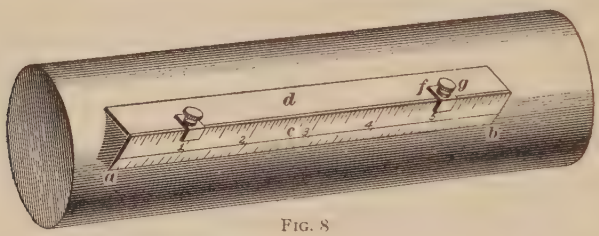


FIG. 8

the straightedge *d* with two hook clamps *f* that are tightened by means of eccentric pins controlled by the milled heads *g*. When the rule is placed in contact with a shaft, the edges, as *a b*, are always parallel to the center line of the shaft; hence, in laying out a key seat, the side lines can be drawn by scribing along the edge *a b*, the width laid off with a pair of dividers, and the length laid off from the graduations along *a b*.

INSTRUMENTS FOR COMPARING AND TRANSFERRING MEASUREMENTS

26. Inside and Outside Calipers.—Calipers are of many shapes and sizes, and are perhaps more extensively used than any other tool in the machine shop. They are used to measure either the diameter or length of a piece of work, from a small fraction of an inch to several feet. The simplest forms of calipers are the **firm-joint calipers,** shown in Fig. 9. The one illustrated in (*a*) is an *outside caliper* used for taking outside measurements of shafts, wheels, and similar pieces, and that shown in (*b*) is its companion tool, the *inside caliper*, which, as its name indicates, is used to measure the diameters of holes or the distance between two objects.

Additional forms of outside and inside calipers, shown in Fig. 10 (*a*) and (*b*), are the **spring calipers,** so called because the pressure of the spring *a* always keeps the leg *b* snug against the nut *c*. The nut *c* may be either a solid or a spring nut. If it is a spring nut, and the pressure is relieved by pressing the legs together, the nut will slide freely on the screw. The thread of the spring nut will reengage with the screw on the slightest pressure.

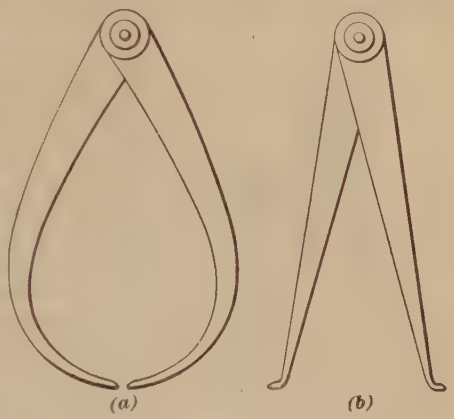


FIG. 9

The spring calipers shown in Fig. 11 are used for measuring the outside diameter of a threaded piece of work, such as a screw, and are called **thread calipers.** The ends *a* and *b* of the legs are made wide, so that they will extend across the tops of two or more threads.

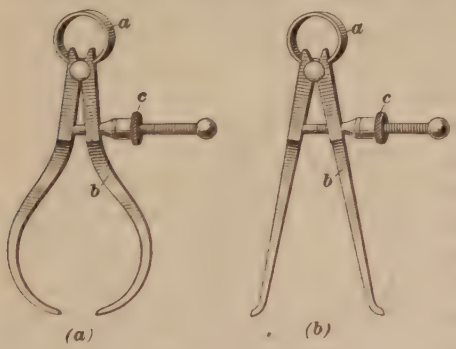


FIG. 10

27. The forms of calipers shown in Fig. 12 are called **transfer calipers.** They are used for making inside and outside measurements under such conditions that the calipers must be closed or opened in order to be removed from the place where the measurement is taken. For example, in calipering the dimension *a*, Fig. 13, the calipers must be opened to be removed from the work; and in calipering the dimension *b* they must be closed in order to be removed. Ordinary calipers cannot be

used in such cases; but the dimensions may easily be measured by the use of transfer calipers. The legs *a* and *b*, Fig. 12 (*a*), of the calipers are first clamped together by pressing the slot *c* over the shank of the screw *d* and then turning the screw down tightly. The calipers are then applied to the piece of work and are set to the exact measurement, which may easily be done, as the leg *e* is free to move. After the calipers are set, the screw *d* is loosened, and the legs *a* and *e* are pressed apart so that the calipers may easily be removed. The legs *a* and *b* are then clamped together again by the screw *d*, as at first; when this has been done, the distance between the points of the legs *a* and *e* will correctly measure the dimension taken from the piece of work.

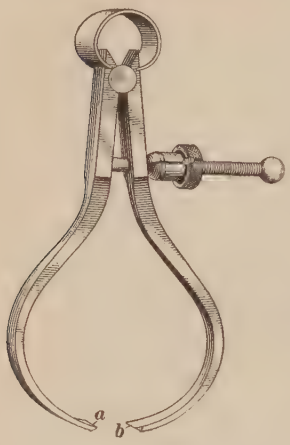


FIG. 11

28. The calipers shown in Fig. 12 (*a*) have screw adjustments in order to enable them to be set accurately to the desired dimension. The inside calipers illustrated in (*b*) are used in the same way as the outside calipers, and show this adjustment clearly. In making a measurement, the calipers are first set roughly to the required dimension, and then the screw *f* is turned until the exact measurement is obtained. Turning the screw *f* right-handed moves the legs *a* and *e* together against the action of the spring *g*, and turning it left-handed allows the spring to press the legs apart. Outside calipers may be set directly to a graduated rule, or they may be set to standard gauges or to pieces to be duplicated and then tried on the work. Inside calipers are

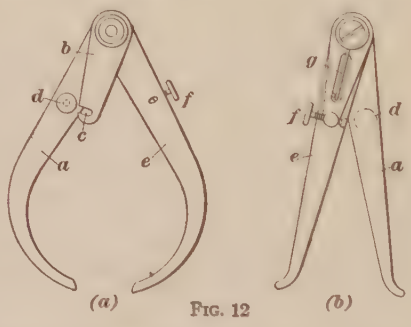


FIG. 12

also set directly to holes either in gauges or in the work, and outside calipers are in turn set to them and tried on the piece under operation. These calipers are used in connection with standard gauges or rules, or for the comparison of one size with another.

29. Care in Setting Large Calipers.—Unless proper care is taken in setting large calipers, an error may be made because of the flexibility of the legs. The amount of this error may be found by making a simple test. A pair of large calipers is opened as wide as possible and is laid flat on the bench, after which an iron bar is placed between the points, so that the calipers measure exactly the length of the bar. If the calipers are now picked up and held by the joint, with the legs hanging down, and are again applied to the bar, it will be found that the points will not go over the ends of the bar without springing the legs apart. The

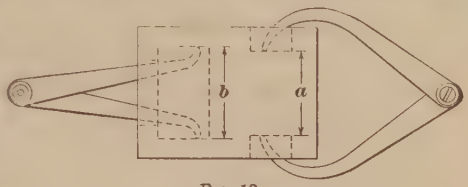


FIG. 13

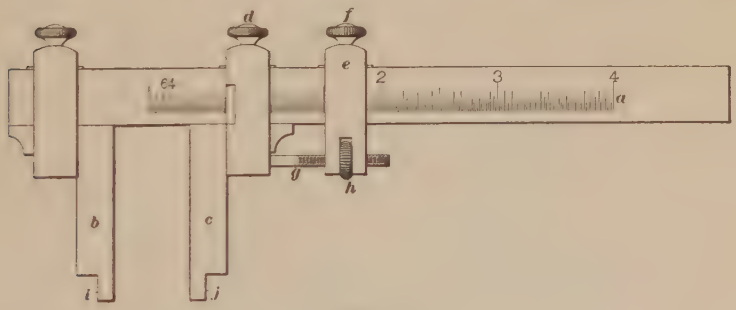


FIG. 14

shortening of the distance between the points of the calipers is due to the flexibility of the legs and the change of position. It follows, therefore, that in setting large calipers, they should be held in the same position as that in which they are to be applied to the work.

30. Caliper Square.—The caliper square, shown in Fig. 14, is a measuring instrument with which line and end

measurements are made at the same time, to obtain the size of work. It consists of a graduated beam *a* fitted with a head, or jaw, *b*, whose inner surface is straight and at right angles to the beam. A sliding head *c* is carefully fitted to the beam, to which it can be clamped by means of a small thumbscrew *d*. The sliding head carries a jaw whose inside surface is exactly parallel to that of the fixed jaw. On the better grade of instruments is fitted another sliding head *e*, which can be clamped to the beam by means of a screw *f*. The two sliding heads are connected by a fine-threaded screw *g*, which is fixed to the head *c* and passes through a clearance hole in the head *e*. A nurled nut *h* is set into a slot cut in the head *e*, and fits over the screw *g*. A very sensitive adjustment is thus made possible, as, by first clamping the head *e* and slightly turning the nut *h*, the sliding head *c* can be moved a very small amount with the greatest ease. The sliding head *c* must always be unclamped when it is to be moved.

31. The edge of the sliding head *c*, Fig. 14, forms the zero line of the instrument. To read the opening of the jaws, therefore, it is necessary to note the position of the edge of the sliding head with reference to the graduation on the beam. Most caliper squares are adapted for both inside and outside measurements; thus, the jaws *i* and *j* are used for inside measurements. The outside edges of these jaws are parallel to each other and to the inside edges of the jaws *b* and *c*. Evidently, the measurement desired would be greater than the reading obtained by an amount equal to the thickness of the jaws *i* and *j*. Hence, for inside measurements, it is necessary to add to the reading obtained an amount equal to the thickness of the jaws. In most cases this amount is $\frac{1}{4}$ inch, and denotes the smallest inside measurement possible with the caliper square.

INSTRUMENTS FOR LAYING OUT WORK

32. Dividers and Trammels.—One type of dividers is shown in Fig. 15, although there are many forms and sizes of this instrument. Dividers are used for drawing circles, spacing

off distances, and subdividing circles or lines. The legs *a* and *b* are pointed at the ends and are held apart by the action of the spring *c*. The points are adjusted accurately by means of the nut *d*.

Trammels, shown in Fig. 16, are merely large dividers. They differ from ordinary dividers in that they consist of two movable heads *a* and *b* that are generally clamped to a bar of wood *c*. If the work is varied, several bars of different lengths should be provided. The tool illustrated is provided with inside and outside caliper points *d* and *e*, and long and short divider points *f* and *g*, the latter being shown in place in the movable heads. The ball points *h*, *i*, *j*, *k* shown in the center are for use in case circles must be drawn or spacing done from holes in partly finished work, the ball making it possible to locate one point in the center of the hole. The heads *a* and *b* are secured to the bar *c* by the clamp screws *l* and *m*.

FIG. 15

The **universal dividers** shown in Fig. 17 consist of a short bar *a* carrying a scriber *b* whose holder *c* is bent. The point *d* is held in a holder *e* that is free to slide on the bar *a* when the adjusting nut *f* on the screw *g* is turned. The nut *f* is held in a slot in a clamp *h* that is fixed on the bar by a screw *i*. The nut *f* and the screw *g* are used when setting the dividers very accurately. The holder *c* may be reversed, thus allowing lines to be scribed close to a shoulder. The point *j* may be substituted for the point *d* when a circle is to be scribed around a drilled hole.

The **hermaphrodite calipers** are a combination of the outside calipers and the dividers, in that one leg is an outside-caliper leg and the other is a divider leg. This tool is used for laying out work on which lines must be drawn parallel to an edge of a piece.

33. Scratch Gauge.—The scratch gauge, a convenient form of which is shown in Fig. 18, is generally constructed from a

round bar *a*, and has a pin through one end or a thin steel star *b* screwed to the end, as shown in the illustration. A movable guide *c*, hardened on its face and held by a thumbscrew, may be located in any position on the bar. With this tool a variety of operations may be performed in laying out work in which lines must be drawn parallel to an edge. The guide *c* is pressed against the edge of the piece, and the gauge is drawn along, when the pin or star *b* will scribe the desired line.

34. Center Square.—The center square, shown in Fig. 19 (*a*), derives its name from the fact that it can be used con-

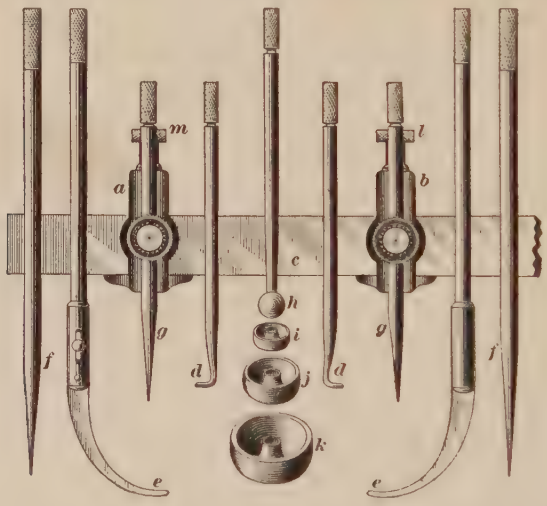


FIG. 16

veniently for finding the centers on the ends of cylindrical work. The stock is so placed that its two legs *a* each make an angle of 45° with the blade *c*, and consequently make an angle of 90° with each other; the cross-bar *b* is placed at right angles to the blade. In using the center square it is placed so that both legs are in contact with the work. Then a line is drawn along the blade *c*, which, as it bisects the right angle formed by the square, will pass through the center of the circle. The center square is then placed in a different position, but still in contact with the work, and the process is repeated. The second line will also pass

through the center of the circle; hence, the point where the two lines cross is the center of the circle.

35. Another useful form of center square is illustrated in Fig. 19 (*b*). The body is made of $\frac{1}{12}$-inch sheet steel. The two pins *d* are $\frac{3}{8}$ inch in diameter and $\frac{3}{8}$ inch long, and are so placed that a line *b b* drawn so as to touch them will be square with the face *a a* and with the inner sides *c* equidistant from *a a*; the face *e e* is made at an angle of 45° with the face *a a*. This tool is used in centering work for the lathe; it is easily applied to either the inside or the outside of rings, and is a good square for drawing lines perpendicular to any surface or edge.

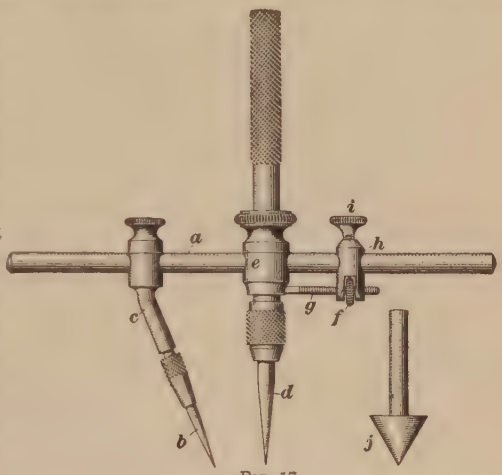


FIG. 17

36. Surface Gauges.—A surface gauge consists of a flat base to which is attached a spindle that carries an adjustable scriber. Fig. 20 shows a good form of surface gauge, which

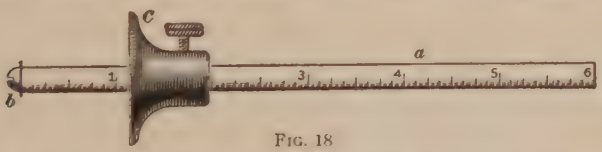


FIG. 18

consists of a rectangular base *b* carrying a spindle *a*, to which is attached the scriber *d*. The scriber can be set at any height or angle within the capacity of the instrument, and then clamped by means of the nut *e* and the clamp *c*. The spindle *a* can be set at any desired angle and clamped by means of the nut *f*. A

fine adjustment for swinging the spindle is provided by means of the lever *g* and the thumbscrew *h*, the lever *g* being pivoted on the inner end of the screw *i*, so that it can be moved by the screw *h*.

The surface gauge may be used for drawing lines parallel to a given flat surface, or for setting a given line or surface parallel to another surface. In the former case, the base *b* is placed on the given surface, as a planer table, and the point of the scriber *d* is set to the required distance from the surface

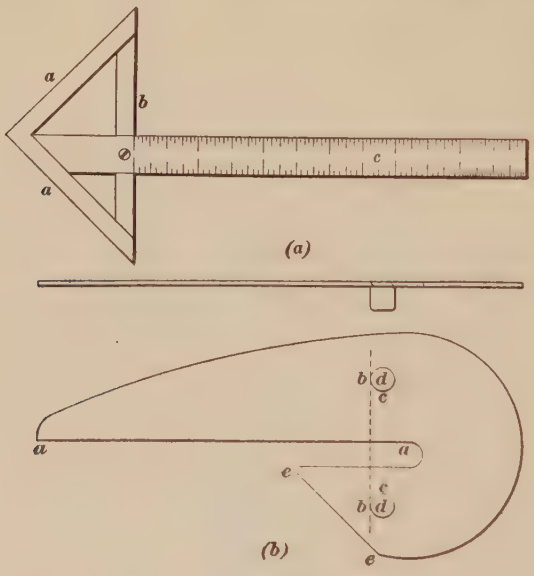


FIG. 19

and used to draw the required line. For setting a line parallel to a given surface, the piece on which the line is drawn is adjusted until the point of the scriber will follow the line as the surface gauge is moved along the guiding surface.

37. Plumb-Bobs.—The plumb-bob serves to determine a vertical straight line; it is made in a variety of forms, and has many uses in the machine shop. The plumb-bob consists of a weight hung from a string or a wire. For some purposes, a nut tied to the end of a string is used, but for most work

a special form of weight is employed. A form that takes little space and has many advantages is shown in Fig. 21 (*a*). It is made by drilling out a steel rod *a* and filling the space *b* with mercury, which is held in place by the screw *c*. Through the cap *d* is a small hole, which is counterbored in the bottom to hold the knot in the line, which should be of the braided or woven variety. The small diameter of this weight makes it particularly useful when hung near a partition or an upright, or in windy places. The point is ground true.

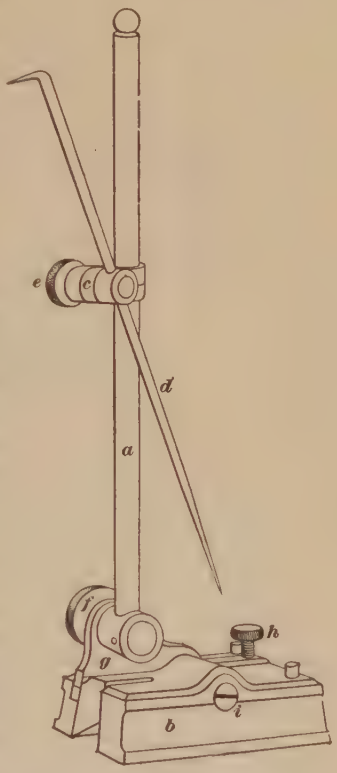


FIG. 20

38. A very common form of plumb-bob is that shown in Fig. 21 (*b*); it is often made with a brass body *e* having an inserted steel point *j* and the usual cap *f* for holding the line. This plumb-bob has most of its weight at the upper end, and therefore is somewhat unsteady. A better form for use where great accuracy is desired is that shown in (*c*). This plumb-bob is made with a brass body *g* having its greatest weight at the lower end to insure steadiness. The point *h* fits the tapered hole through the body *g* and is held in position by the cap *i*. The point is readily removed for repairs, and may be used without the body by simply screwing on the cap. The point may be ground by providing a sleeve about $1\frac{1}{4}$ inches long, reamed to the same taper as the body and turned parallel outside, so that it may be held in the chuck of a grinding machine. If the line is very long, so that the plumb-bob tends to swing, it may be allowed to hang in a pail of water or oil, in order to steady it.

39. Spirit Levels.—Spirit levels are used for testing horizontal and vertical lines and surfaces. The essential feature of a level is a glass tube or vial nearly filled with alcohol or ether and sealed at both ends. The air remaining in the tube forms a small bubble that is always found at the highest point of the glass tube. The tube is slightly bent, as shown in Fig. 22 (*a*),

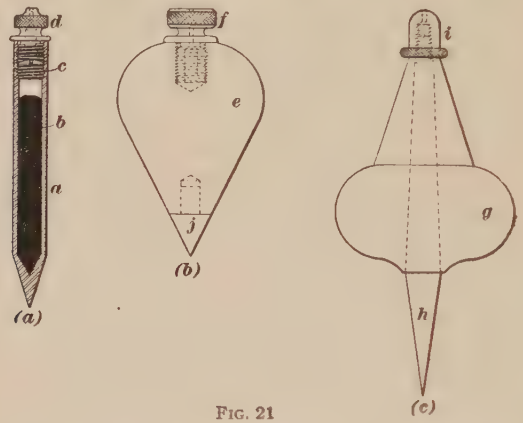


FIG. 21

and is mounted with its convex side up, so that the bubble will come to rest quickly. A line is scratched on the glass at *a*, coinciding with the center of the bubble when the level is truly horizontal. For work requiring the greatest accuracy, use is made of a ground-glass tube, that is, a tube ground on the inside to a barrel shape, as shown somewhat exaggerated in (*b*). The less curve there is in the glass, the more sensitive will be the

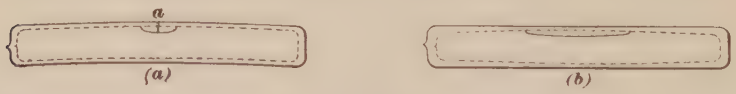


FIG. 22

level, and the longer will be the bubble. The bubble in the ground glass is usually much longer than that in the bent glass. The body, or frame, of the carpenter's level is generally made of hardwood, the best levels being built up of several well-seasoned strips glued together. Fig. 23 shows the ordinary form of iron level often used in the machine shop.

40. When great accuracy is required, the form of level shown in Fig. 24 may be used. The base *a* is from 12 to 18 inches long and from $1\frac{1}{4}$ to $1\frac{3}{4}$ inches wide, with a V groove $\frac{3}{4}$ inch wide extending its entire length, as shown at *b* in the end view. The base is scraped perfectly flat and parallel, and the V is carefully tested to insure that it is exactly parallel with the edges. The glass *c*, which is preferably ground and graduated, is held in a casing *d* that may be adjusted as to height by means of the nuts *e*. A second glass *f* is set at right angles to the glass *c*, to be used for testing vertical surfaces, the base in this case being laid against the vertical surface to

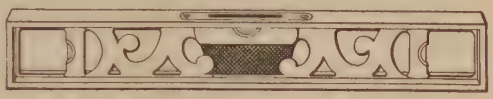


FIG. 23

FIG. 24

be tested. The glass *g* is of service when the level is used for testing horizontal cylindrical work. The work fits into the groove in the base, as illustrated in Fig. 25, and the glass *g*, Fig. 24, serves to show when the level is held horizontal, as indicated by the full lines, Fig. 25. It should not be tilted to one side or the other as shown by the dotted lines, or it will not indicate a true level. In some makes, the crosswise glass is omitted.

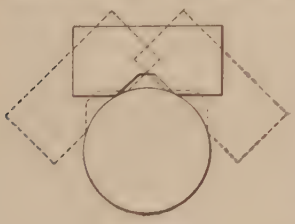


FIG. 25

41. Testing of Levels. Levels of the best makes are very sensitive to changes of position. If a good level is laid on a surface plate and a piece of tissue paper is slipped under one end, the bubble will move about $\frac{1}{32}$ inch. In order to test its accuracy, a level is placed on a surface plate that is known to be truly horizontal, and is then turned end for end. If the level is

accurate, the bubble will not change its position, whatever that of the level. The level should next be tilted on one edge and then on the other; if the bubble remains in the center during these operations, the glass is correctly set. Two short rollers of exactly the same diameter should now be laid on the surface plate, and the level should be placed on them, with about $\frac{1}{2}$ inch of the end of the V on each roller. The level should then be rocked from side to side, and if the bubble remains central the level is correct; if it does not remain central, the groove should be scraped until it does. If, in selecting or setting a glass, it is found to be perfect in the horizontal position, and when set up edgewise will always show high on one end and is the same when reversed, the fault is due to a slight defect in the glass, probably caused when the opening was sealed, one end having been made a little larger than the other. It can be noticed only when the level is rotated on the rollers or on a shaft, as shown in Fig. 25.

INSTRUMENTS FOR MEASURING DEPTH

42. Measuring Depth With Rule and Straightedge. The depth of a cavity in a piece of work may conveniently be measured by the use of a standard rule and a straightedge. The straightedge is laid across the cavity and the rule is then inserted in the cavity, and at right angles to the edge of the straightedge. The depth of the cavity, reckoning from the bottom of the straightedge, may then be read directly from the rule at a point even with the lower edge of the straightedge. If the bottom of the cavity is flat and level, the rule will rest evenly on it and stand perpendicular to the straightedge. If the bottom of the cavity is

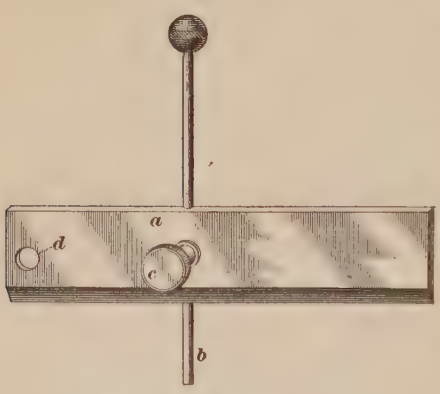


FIG. 26

curved, however, a small rod must be used instead of the rule. The rod is ground to a point and is held perpendicular to the straightedge with the pointed end resting on the bottom of the cavity. A line is then scratched on the rod, even with the lower edge of the straightedge, and the rod is removed. The distance from this line to the point is then the required depth.

43. Depth Gauge.—For testing the depth of holes or grooves, the depth gauge is frequently used. One form of this instrument is shown in Fig. 26. It consists of a straightedge *a*, to which is attached a wire *b*. The amount that the wire projects beyond the straightedge can be regulated, and the wire then may be clamped to the straightedge by means of a clamp controlled by the nut *c*. Sometimes the wire is replaced by a small graduated bar or scale, so that the depth can be read directly, without being compared with a rule. If the hole whose depth is to be measured lies close to a shoulder, it may be necessary to shift the clamp *c* to the hole *d* at the end of the straightedge and to attach the wire *b* to the clamp at that point.

INSTRUMENTS FOR ANGULAR MEASUREMENT

44. Combination Bevel.—The combination bevel, shown in Fig. 27, is an instrument that may be used for measuring angles. The stock *a* and the split blade *b* form the ordinary bevel, and the slotted blade *c* may be removed, when desired. The numbers 30°, 45°, and 60° represent the angles the respective edge make with the adjacent sides. These angles make the tool convenient for measuring in corners, and it may be used for measuring angles of 30°, 45° and 60° direct. The instrument is set either to an angle desired to be transferred, or by means of a protractor, and is a light and convenient tool to use.

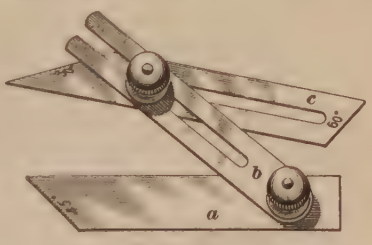


FIG. 27

45. Protractor.—For the measurement of angles, an instrument called a protractor is used. The unit of angular measurement is $\frac{1}{360}$ part of a circle, which is called a degree. The degree is subdivided into 60 parts, called minutes. A minute is subdivided into 60 parts, called seconds. Smaller divisions of the degree are expressed as decimal parts of the second.

46. Protractor With Guide Pin.—The protractor shown in Fig. 28 consists of a thin plate of steel or brass, semicircular in shape, with the center of the semicircle at *a*. The curved edge is divided into 180 equal parts, and each division thus represents 1°. For convenience the degrees are numbered from 0 to 90, from each end of the semicircle. A center guide pin *b* is so placed that, if a straightedge is set against the flat surface of the pin, the edge in contact with the pin will pass through the center of the protractor. This guide pin is a rivet with half of the head cut away, and is loose enough to conform readily to the edge of a straightedge. Should the angle to be measured be larger than 90°, the reading must be subtracted from 180°. Thus, the angle *c a d* is read off directly as 55°; whereas, the angle *c a c*, being greater than 90°, is equal to 180° − 55° = 125°. This form of protractor is very convenient for setting the combination bevel. The stock of the bevel is placed against the straight bottom edge of the protractor. The blade is adjusted so as to lie flat against the center guide pin and cross the graduated edge at the correct division.

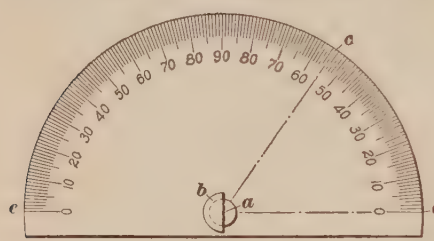


FIG. 28

47. Bevel Protractor.—The protractor as used by the mechanic makes measurements by a combination of line and end measurements. In this modified form, it is commonly known as a *bevel protractor*. To suit different purposes and individual preferences, the bevel protractor is made in a number

of different forms by the various manufacturers. All these forms embody the same principle of construction, which is the combination of two straightedges with a graduated circle or part of a circle.

48. All the main features of the bevel protractor are well exhibited in Fig. 29. The arm a is attached to the graduated

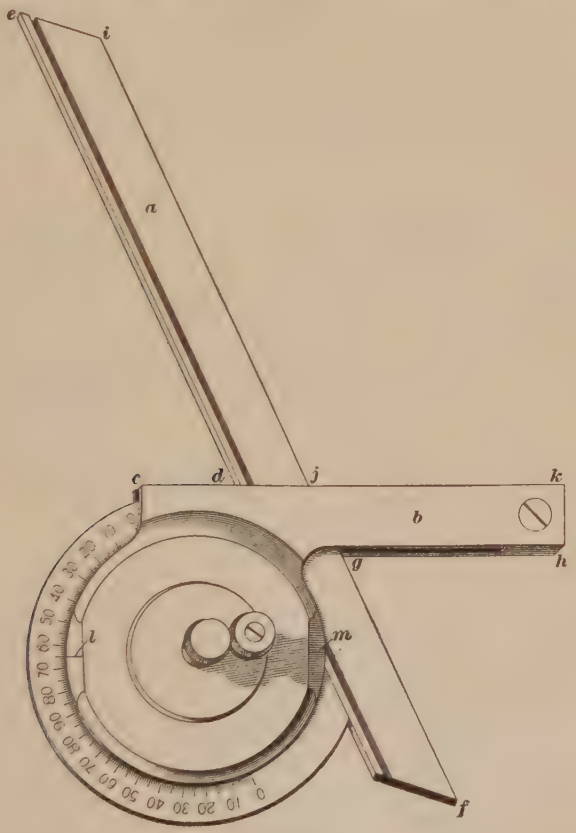


FIG. 29

semicircle, and the straightedge b forms one piece with the circular part on which the lines l and m are marked. A line passing through l and m passes also through the center of the protractor and is parallel to the edge $c\,k$. The arm and the

straightedge are pivoted at the center of the graduated semicircle. The zero lines l and m are so located that they exactly coincide with the zeros of the graduated semicircle when the arm a and the straightedge b are in the same straight line. For convenience, the straightedge b is slotted, to allow the arm a to pass through it; in consequence of this, either the arm or the straightedge can be rotated through 360°. The arm a may be slipped back and forth its full length, and can be clamped at any point to the part on which the graduations are marked.

49. To make a measurement with the bevel protractor shown in Fig. 29, the arm a and the straightedge b are brought

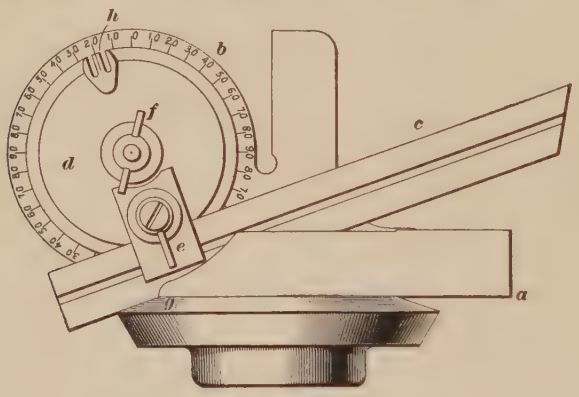


FIG. 30

in contact with the work; the angle is then read off by observing the position of the zero line l with regard to the graduations. Some judgment is required to read the angle correctly; that is, if the angle measured is smaller than 90°, it can be read off directly, but if it is larger than 90°, the reading must be subtracted from 180°. When the arm a stands in such a position that the angles $c\,d\,e$ and $i\,j\,k$ are equal, each of these angles is 90°, and the mark l stands at 90 on the scale. The angle $f\,g\,h$, also, is 90° when the mark l is at 90. But when the arm a is swung to the left, as shown, the angle $i\,j\,k$ is made greater than 90° and the angles $c\,d\,e$ and $f\,g\,h$ are made less than 90°. The mark l then stands opposite 65 on the scale. Therefore, as

the angle $i\,j\,k$ is greater than 90°, its value must be found by subtracting the scale reading from 180°; that is, the angle $i\,j\,k = 180° - 65° = 115°$. As the angles $c\,d\,e$ and $f\,g\,h$ are smaller than 90°, their values are read directly from the scale; that is, each is 65°.

50. Another form of bevel protractor is shown in Fig. 30. It has a stock *a* fixed to a graduated circle *b*. In the center of the graduated circle is a pin on which the disk *d* rotates. The arm *c* is fastened to the disk by the thumbnut and clamp *e*, and the disk can be held in any position by the thumbnut *f*. The protractor is shown measuring the angle of the face of a bevel-

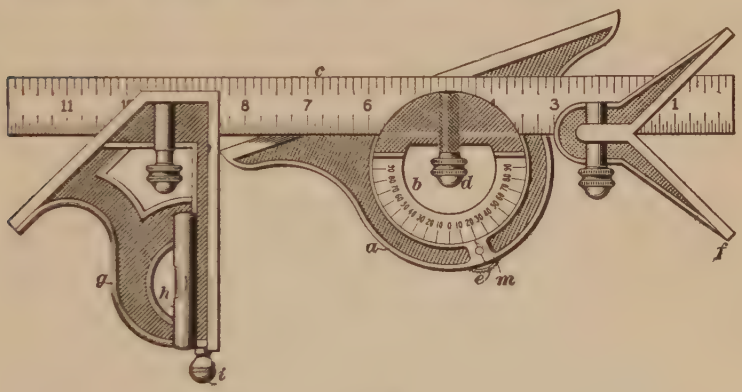


FIG. 31

gear blank. The edge of the stock *a* is placed across the work, and the arm *c* is brought in contact with the face *g* of the gear and locked by means of the nut *f*. The line *h* on the disk *d* coincides with the twentieth division on the graduated circle; hence, the angle of the face is 20°.

51. A simpler protractor is shown in Fig. 31. It consists of a stock *a* having a graduated rotating holder *b* for the blade *c*, which after setting may be clamped in any position by the nut *d*. The holder *b* is graduated in degrees through one-half of its circumference, or 180°, and is clamped in any desired position by the thumbscrew *e*. With this instrument the same care is to be taken that is necessary in reading the bevel protractor

shown in Fig. 29. A center-square head *f*, Fig. 31, with which the protractor is supplied, furnishes an excellent means for centering lathe work. The head *g* makes an adjustable square and a 45° angle, and is provided with a level *h* and a scriber *i*. These various fittings are not all used at one time. Each is removable, and may be attached easily when required. The straight edge of the stock *a* is in line with the upper edge of the blade *c* when the mark *m* is opposite the zero of the scale. This scale is graduated from 0° to 90° in each direction; hence, the angle between the edge of the stock and the top edge of the blade is always 180° minus the reading on the scale. In the illustration the reading is about 19°, and consequently the angle at the upper edge of the blade is $180° - 19° = 161°$. The angle between the lower edge of the blade and the edge of the stock is equal to the reading on the scale, and is about 19° in this case.

FIXED MEASURING INSTRUMENTS

52. Straightedges.—The straightedge is a bar of metal having its edges true to a straight line. It is used for testing surfaces, edges, etc. Straightedges are made in several forms, to suit individual preferences. They either have a rectangular cross-section, as shown in Fig. 32 (*a*), or are beveled on one edge, as in (*b*). For very accurate work, straightedges are sometimes made as shown in Fig. 33. When thus made, they are extremely sensitive, owing to the fact that they touch the work along a line only, and a very small deviation will show daylight between the work and the straightedge in contact with it.

FIG. 32

53. Try Square, or Steel Square.—A gauge made in either of the forms shown in Fig. 34, is called a try square, or a steel square. It is used for testing right angles, that is, angles of 90°. The hardened-steel squares made by several manufacturers are especially fitted for such work as tool making, jig making, etc. They are made in various sizes from $1\frac{1}{2}$ inches to 24 inches or over, the size being measured

on the inside of the blade. The smaller sizes are usually made as shown in (*a*), with a blade *a* fastened by soldering and rivets to the stock *b*. In the larger sizes, the stock and the blade are usually united by screws, as shown in (*b*); this allows them to be repaired more readily.

54. Graduated Square.—A form of square similar to the steel square described in the previous article, graduated on the back edge, but not hardened, is known as the graduated square. It is an excellent substitute for the hardened instrument, especially on the laying-out table. The well-known carpenter's square, which is of the graduated type, is used for a large variety of work in the machine shop. For many ordinary uses it answers the purpose perfectly, but it is not sufficiently accurate for the best grades of work.

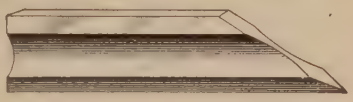


FIG. 33

55. Use of Squares.—Only the edges of the blade of a try square and not the corners or sides should be employed in testing work. In using the square, the beam or stock is placed at right angles to the surface to be tested, and the blade is brought

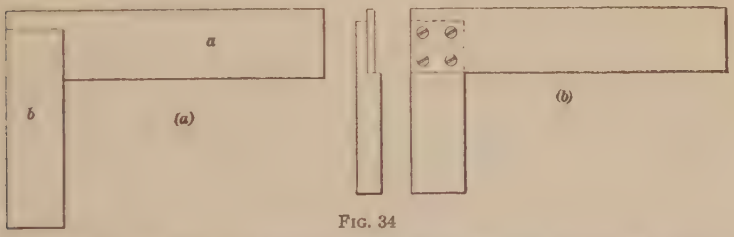


FIG. 34

against it. If the surface touches the edge of the blade along its whole length, the surface is at right angles to that on which the stock of the square rests. Sometimes the square must be used in such a position that it is impossible to see by the eye whether the work is true or not. In such a case, the sense of touch may be used. Two strips of paper of the same thickness are placed between the blade of the square and the surface being tested, one strip being put at each end of the blade. The strips

are then pulled gently. If the same strength of pull is required to draw both strips out from behind the blade, the surface is true; but if one strip draws out more easily, the surface slants away from the blade under that strip.

56. Adjustable Square.—The adjustable square, illustrated in Fig. 35, forms a combination having many useful applications. The blade *a* is held in the stock *b* by a hook clamp that enters the groove *c* in the blade, and is tightened by means of the nut *d*. The groove *c* runs the full length of the blade, so that the stock may be set at any point throughout its length.

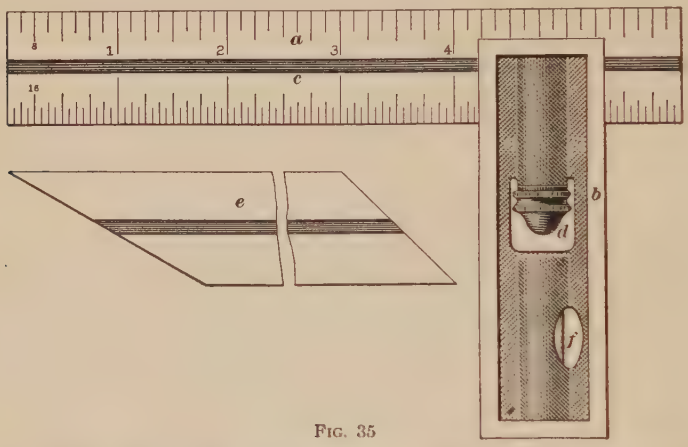


FIG. 35

The square may thus be adjusted to the work in hand, which could not be done with an ordinary try square having a fixed blade. A special bevel blade *e*, with a 45° angle at one end and a 30° angle at the other, may be substituted for the graduated blade whenever these angles are to be laid off or tested. This special blade provides the angles required in laying out either a hexagon or an octagon. The stock is also provided with a level at *f* that may be used in testing either a vertical or a horizontal surface. It should be borne in mind that a square is perfect only when the blade and the stock are exactly at right angles to each other, and that a fall or any careless use is liable to destroy its accuracy. The adjustable square is not so accurate as the steel square.

57. Classes of Gauges.—Gauges may be divided into two general classes, namely, *reference gauges* and *working gauges*. The first class includes all gauges that represent ultimate standards of reference, accurate subdivisions of these standards, or some arbitrary size or shape that must be preserved. The bars representing the standard yard, kept by the Government, are reference gauges. The second class includes all gauges that are used in the shop for making linear and other measurements. As reference gauges are used very rarely, and then not in the shop, this Section will deal only with working gauges.

58. Cylindrical Gauges.—For testing the inside and outside dimensions of cylindrical work of relatively small diameter, the cylindrical gauges shown in Fig. 36 have a wide range of application. These are also known as *plug and ring*

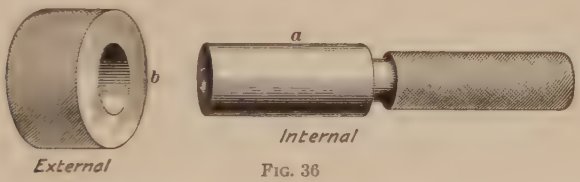
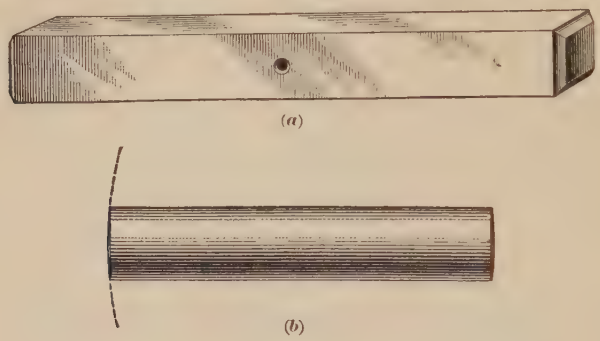


FIG. 36

gauges. The plug gauge *a* is a hardened-steel cylinder that is ground and accurately lapped to size and provided with a suitable handle. The ring gauge *b* is a hardened-steel ring ground and lapped inside to fit the plug gauge accurately. The plug gauge is used for testing inside dimensions, and the ring gauge for outside dimensions.

59. End-Measuring Gauges.—A form of end-measuring rod is shown in Fig. 37 (*a*), consisting of a square hardened-steel bar whose ends are ground and lapped until they are plane surfaces parallel to each other. For testing the size of holes beyond the range to which a plug gauge is limited, because of its weight and cost, an end-measuring rod of the form shown in (*b*) may be used. The ends of the rod are made part of a sphere equal in diameter to the length of the rod; consequently, the rod can be used for any kind of internal measurement without

danger of cramping. It is also useful for setting calipers, comparing other working gauges, measuring between parallel sur-



(*a*) (*b*)

FIG. 37

faces, either plain or curved, and similar work. The form of rod shown in (*a*) cannot be used for internal measurements, as it would cramp, because its ends are not spherical. End-measuring gauges are also made in the form of circular disks, like that shown in Fig. 38. This gauge is made with a circular hole, for ease of manufacture, and also to allow it to be used with a handle inserted therein. The circular form makes the disk very convenient for setting calipers. When used for testing purposes, a very delicate contact can be obtained, since it is only in line contact with the measuring instrument.

60. Caliper Gauge.—The standard caliper gauge, two forms of which are shown in Fig. 39 (*a*) and (*b*), is preferable to any other style of gauge for many classes of work. In the smaller sizes it is usually made with one end for inside and the other for outside measurements, as shown in (*a*); in the larger sizes, in order to keep its weight within a reasonable limit, the gauge for internal measurement is made separate from that intended for outside measurement, as shown in (*b*). The gauge intended for outside measurement has its measuring surfaces ground and lapped to be plane surfaces parallel to each other. When the gauge

FIG. 38

intended for internal measurement is to be used for circular holes, its measuring surfaces are formed as parts of the surface

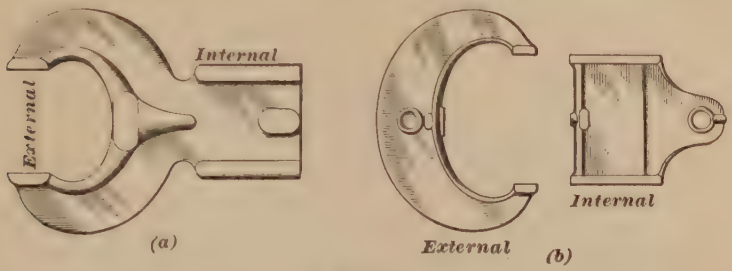


FIG. 39

of a cylinder. For measuring between parallel plane surfaces, its measuring surfaces should be planes parallel to each other.

61. Limit Gauges.—The working gauges thus far described simply determine whether the work is of the true size; they do not show the amount of variation from this size, nor do they tell whether the variation is sufficient to condemn the work. Suppose that two working gauges are employed, of which the one is made to the greatest allowable size the work can be, and the other one is made to correspond to the smallest

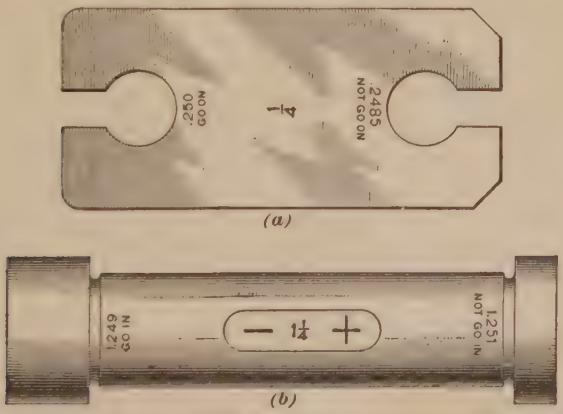


FIG. 40

allowable size. Then, if the larger gauge goes over the work and the smaller one does not, it follows that the amount the

work varies from the true size must lie somewhere between the limit set by the two gauges; hence, the variation is not sufficient to condemn the work. A pair of such gauges forms a limit gauge. A limit gauge for external measurements is shown in Fig. 40 (*a*). If the end marked GO ON will fit over the work and the end marked NOT GO ON will not fit over the work, it follows that the piece of work has a size somewhere between .2485 inch and .250 inch. A gauge for internal measurements is shown in (*b*) and is applied in a similar manner to that shown in (*a*). It must not be inferred that the two forms shown are the only forms limit gauges can have; they may be made in many ways, to suit the character of the work for which they are to be used.

62. Screw-Thread Gauges.—Special gauges for measuring the sizes of screws and screw threads are shown in Fig. 41.

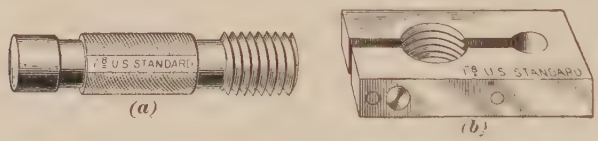


FIG. 41

The internal gauge shown in (*a*) consists of a threaded cylinder made to standard size at one end, and on the other end a true cylinder of a diameter equal to that over the bottom of the thread. The threaded end is used to test the thread on the inside of a hole, as in a nut, whereas the plain end forms a gauge for testing the size to which the hole is bored or drilled before the thread is cut in it. The external gauge shown in (*b*) is threaded to fit the internal gauge, and is adjustable for wear within reasonable limits; it is used for testing the size of screws, bolts, taps, etc. For shop use, these gauges are made of hardened steel; for reference purposes they are left soft.

63. Screw-Pitch Gauge.—The advance of a screw thread in one complete turn, measured in a direction parallel to the axis of the screw, is the pitch of the thread; it is equal to 1 divided by the number of threads per inch. The screw-pitch gauge is a gauge used to measure the number of threads per inch of a

screw, and is made in various shapes and sizes to suit threads of different forms and pitches. A screw-pitch gauge intended for the measurement of 60° sharp V threads is shown in Fig. 42. It consists of a number of thin leaves pinned at each end of the handle *a* so that all may be folded inside the handle when not in use and any one leaf may be swung out when needed. This particular gauge may be used for screws having from 9 to 40 threads per inch, and is suitable for inside or outside threads. Each leaf is stamped with an integral number denoting the number of threads per inch for which it is intended; also, it bears a decimal number that denotes twice the depth of the thread. By subtracting this decimal from the outside diameter of the screw, the diameter at the bottom, or root, of the thread is obtained.

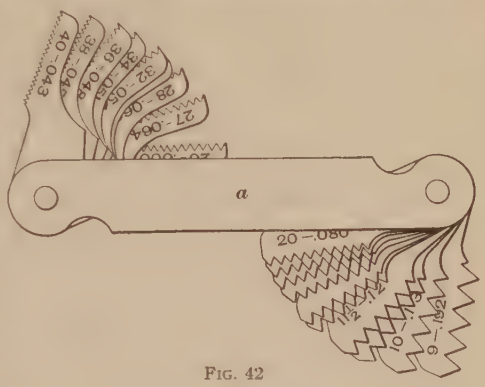


FIG. 42

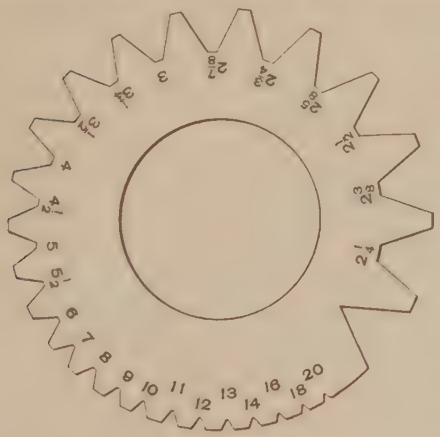


FIG. 43

64. Tool Gauges. A tool gauge is a gauge that is used to determine the proper size and shape to which a tool must be ground in order that it may cut a correct thread of the desired pitch. As threads are of different forms and pitches, tool gauges must differ in shape and size. A tool gauge to be used to determine the form of a tool intended for cutting United States standard

threads is shown in Fig. 43. It is a ring of metal bearing a series of 60° notches, each of which is marked with a number. The depth and form of the notch determines the size and shape to which the point of the tool must be ground, and the number denotes the number of threads per inch of the screw to be cut by that tool. A worm-thread tool gauge is shown in Fig. 44. It is used to test the shape and size of a tool for cutting worm threads. The numbers denote the number of threads per inch.

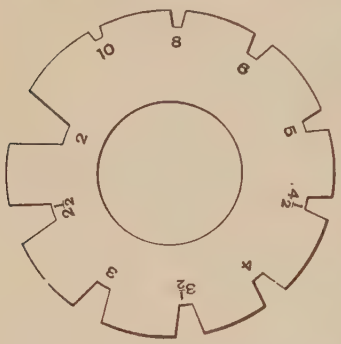


FIG. 44

65. Center Gauge. — The gauge shown in Fig. 45 is a center gauge, and is also known as a *thread gauge*. It defines the standard angle for lathe centers, 60°, which is almost universally used in America; this is also the standard angle for the sharp or V screw thread and the Sellers, or United States standard, thread. Notches *a* and *b*, having an angle of 60°, are convenient for grinding thread-cutting tools. These notches are cut so that their sides make the same angle with the edge in which they are cut; they can therefore be used for setting thread-cutting tools square with the work.

66. Nearly every center gauge has stamped on it a table, as shown in Fig. 45. Each of the whole numbers from 4 to 26 denotes the number of threads per inch, and the corresponding decimal denotes twice the depth of the sharp or V thread. To find the size of tap drill for a given number of threads per inch, the decimal corresponding to this number of threads per inch is subtracted from the outside diameter of the screw. Center gauges are usually graduated on both sides, along both edges, with divisions of the inch that

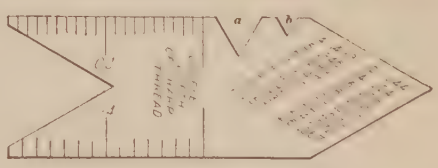


FIG. 45

are convenient for measuring the number of threads per inch on screws. Thus, the side shown in Fig. 45 has 20 divisions to the inch on one edge, and 14 divisions on the other edge. The different numbers of threads per inch for which each graduation is most suitable are those by which the graduation is divisible without a remainder. Thus, the twentieth graduation is suitable for measuring 1, 2, 4, 5, 10, and 20 threads per inch, and also for any multiple of 20, as 40, 60, 80, etc.

67. Decimal Gauge.—The decimal gauge, a form of which is illustrated in Fig. 46, is used for measuring the thick-

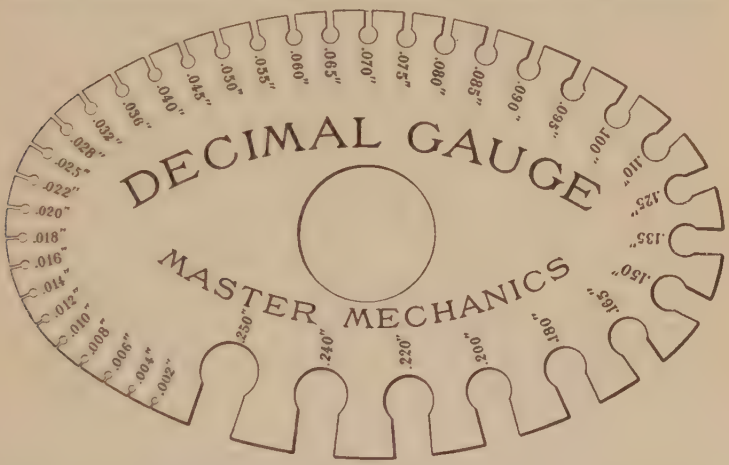


FIG. 46

ness of wire and sheet metal directly in decimal parts of an inch. It is a thin oval plate of metal having a series of slots along its outer edge. The distance between the parallel sides of each slot is indicated by the number stamped at the inner end of the slot. The thickness of wire or sheet metal is determined by finding the smallest slot that will fit over the wire or the sheet.

68. Numbered Gauges.—Numbered gauges express sizes by arbitrarily selected numbers or letters, and are used for gauging metal plate, wire, and small sizes of twist drills. There are a large number of numbered gauges on the market, among

which may be mentioned the United States, American or Brown & Sharpe, Birmingham or Stubs' iron, American Steel and Wire, Russia iron, steel music-wire, Stubs' steel-wire, twist-drill and steel-wire, and machine and wood screw standard. Owing to the confusion caused by the use of so many different gauges, it is best to state the thickness of sheet metal and the diameters of wire or drills by the decimal parts of an inch. Each gauge number or letter denotes some particular thickness, and Tables I to IV are given in order to show the numbers or letters used and the corresponding thicknesses in decimal parts of an inch.

69. Three common forms of numbered gauges for sheet metal and wire are shown in Fig. 47. The notched gauges are

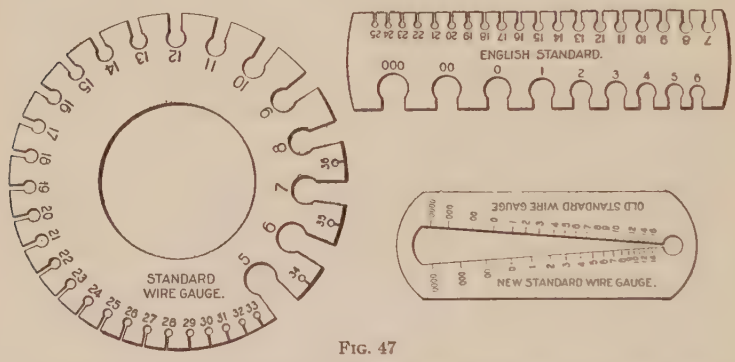


FIG. 47

made like the decimal gauge in Fig. 46, with the exception that they have the sizes of the slots marked by numbers instead of by decimals of an inch. They are used in the same manner as the decimal gauge. The gauge with the triangular opening, Fig. 47, is adapted only for stock of circular cross-section, such as wire and the shanks of screws. It is passed over the wire until it touches on both sides; the division at the point of contact indicates the gauge number of the wire.

70. United States Standard Gauge.—The United States standard gauge, given in Table I, is a gauge established by Act of Congress in 1893 for use in determining duties and taxes levied by the United States on sheet iron, plate iron, and steel. It is used to a limited extent by American rolling mills

TABLE I

SHEET-METAL AND WIRE GAUGES

Gauge Number	Dimension in Decimal Parts of an Inch				Gauge Number
	U. S. Standard	American or Brown & Sharpe	Birmingham or Stubs'	American Steel & Wire	
0000000	.500000000			.49000	0000000
000000	.468750000			.46150	000000
00000	.437500000			.43050	00000
0000	.406250000	.460000	.454	.39380	0000
000	.375000000	.409640	.425	.36250	000
00	.343750000	.364800	.380	.33100	00
0	.312500000	.324860	.340	.30650	0
1	.281250000	.289300	.300	.28300	1
2	.265625000	.257630	.284	.26250	2
3	.250000000	.229420	.259	.24370	3
4	.234375000	.204310	.238	.22530	4
5	.218750000	.181940	.220	.20700	5
6	.203125000	.162020	.203	.19200	6
7	.187500000	.144280	.180	.17700	7
8	.171875000	.128490	.165	.16200	8
9	.156250000	.114430	.148	.14830	9
10	.140625000	.101890	.134	.13500	10
11	.125000000	.090742	.120	.12050	11
12	.109375000	.080808	.109	.10550	12
13	.093750000	.071961	.095	.09150	13
14	.078125000	.064084	.083	.08000	14
15	.070312500	.057068	.072	.07200	15
16	.062500000	.050820	.065	.06250	16
17	.056250000	.045257	.058	.05400	17
18	.050000000	.040303	.049	.04750	18
19	.043750000	.035890	.042	.04100	19
20	.037500000	.031961	.035	.03480	20
21	.034375000	.028462	.032	.03175	21
22	.031250000	.025347	.028	.02860	22
23	.028125000	.022571	.025	.02580	23
24	.025000000	.020100	.022	.02300	24
25	.021875000	.017900	.020	.02040	25
26	.018750000	.015940	.018	.01810	26
27	.017187500	.014195	.016	.01730	27
28	.015625000	.012641	.014	.01620	28
29	.014062500	.011257	.013	.01500	29
30	.012500000	.010025	.012	.01400	30
31	.010937500	.008928	.010	.01320	31
32	.010156250	.007950	.009	.01280	32
33	.009375000	.007080	.008	.01180	33
34	.008593750	.006304	.007	.01040	34
35	.007812500	.005614	.005	.00950	35
36	.007031250	.005000	.004	.00900	36
37	.006640625	.004453		.00850	37
38	.006250000	.003965		.00800	38
39		.003531		.00750	39
40		.003144		.00700	40

for sheet iron, plate iron, and steel, and also for galvanized sheet iron and American planished iron. The gauge numbers are

TABLE II

STUBS' STEEL-WIRE GAUGE

Gauge Letter	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch
Z	.413	1	.227	28	.139	55	.050
Y	.404	2	.219	29	.134	56	.045
X	.397	3	.212	30	.127	57	.042
W	.386	4	.207	31	.120	58	.041
V	.377	5	.204	32	.115	59	.040
U	.368	6	.201	33	.112	60	.039
T	.358	7	.199	34	.110	61	.038
S	.348	8	.197	35	.108	62	.037
R	.339	9	.194	36	.106	63	.036
Q	.332	10	.191	37	.103	64	.035
P	.323	11	.188	38	.101	65	.033
O	.316	12	.185	39	.099	66	.032
N	.302	13	.182	40	.097	67	.031
M	.295	14	.180	41	.095	68	.030
L	.290	15	.178	42	.092	69	.029
K	.281	16	.175	43	.088	70	.027
J	.277	17	.172	44	.085	71	.026
I	.272	18	.168	45	.081	72	.024
H	.266	19	.164	46	.079	73	.023
G	.261	20	.161	47	.077	74	.022
F	.257	21	.157	48	.075	75	.020
E	.250	22	.155	49	.072	76	.018
D	.246	23	.153	50	.069	77	.016
C	.242	24	.151	51	.066	78	.015
B	.238	25	.148	52	.063	79	.014
A	.234	26	.146	53	.058	80	.013
		27	.143	54	.055		

given in the first column and the corresponding thicknesses, according to the United States standard, are given in the second

column. For example, a wire having a gauge number of 18 according to the United States standard gauge, is .05 inch in diameter.

71. American, or Brown & Sharpe, Gauge.—The American, or Brown & Sharpe, standard gauge, given in the third column of Table I, is the gauge used almost exclusively for sheet brass, sheet aluminum, sheet German silver, brazed brass tubing, brass wire, copper wire, and German-silver wire of American manufacture.

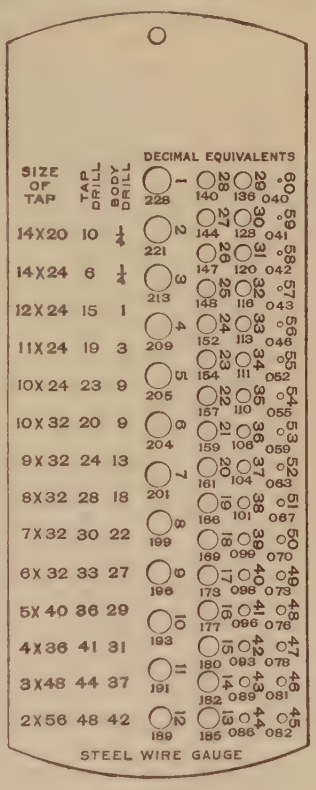


FIG. 48

72. Birmingham, or Stubs', Iron Gauge.—The Birmingham, or Stubs', iron gauge, given in the fourth column of Table I, is the gauge used by the trade for sheet iron, sheet steel, sheet copper, iron wire, Bessemer-steel wire, and seamless tubing of all kinds, practically to the exclusion of all other gauges.

73. American Steel and Wire Company Gauge.—The American Steel and Wire gauge, given in the fifth column of Table I, is a gauge used by the American Steel and Wire Company to gauge its products. This gauge was formerly known as the Washburn & Moen, and this name is still extensively used.

74. Stubs' Steel-Wire Gauge.—The Stubs steel-wire gauge, given in Table II, is the gauge used almost exclusively for tool-steel wire in the form of straight rods, commonly called drill rods. It is also used by some makers for tool-steel wire sold in coils and on spools. Drill rods and wire gauged by this

gauge are usually sold annealed; hence, if such drill rods and wire are used for helical or other coiled springs, the springs must be hardened and tempered in order to retain their elasticity.

75. Twist-Drill Gauge.—The twist-drill gauge, given in Table III, is the gauge used entirely by American manufacturers

TABLE III

TWIST-DRILL AND STEEL-WIRE GAUGE

Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.0292
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

for designating the smaller sizes of twist drills, excepting twist drills known as jobbers' drills. Jobbers' drills are sold directly by their actual size. The twist-drill gauge is used to some extent for steel wire and also for drill rods. A drill and

tap-drill gauge is illustrated in Fig. 48. The tap-drill feature of this gauge consists of the table stamped on the left of the gauge, giving the size of tap drill and body drill for the small sizes of taps in use. A 14×20 tap, for example, means a tap with an outside diameter equal to gauge number 14, Table III, and having 20 threads to the inch. It should be observed that the decimal equivalents stamped on the gauge are carried to only three decimal places, whereas Table III gives the equivalents to four places.

TABLE IV

SCREW GAUGE FOR MACHINE AND WOOD SCREWS

Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch	Gauge Number	Size in Decimals of an Inch
000	.03152	16	.26840	34	.50528
00	.04468	17	.28156	35	.51844
0	.05784	18	.29472	36	.53160
1	.07100	19	.30788	37	.54476
2	.08416	20	.32104	38	.55792
3	.09732	21	.33420	39	.57108
4	.11048	22	.34736	40	.58424
5	.12364	23	.36052	41	.59740
6	.13680	24	.37368	42	.61056
7	.14996	25	.38684	43	.62372
8	.16312	26	.40000	44	.63688
9	.17628	27	.41316	45	.65004
10	.18944	28	.42632	46	.66320
11	.20260	29	.43948	47	.67636
12	.21576	30	.45264	48	.68952
13	.22892	31	.46580	49	.70268
14	.24208	32	.47896	50	.71584
15	.25524	33	.49212		

76. American Screw Gauge.—The American screw gauge, given in Table IV, is the gauge used exclusively for

American machine screws and wood screws made of iron, steel, or brass. The table gives the diameter of the unthreaded cylindrical part or shank of the screw, and is applicable to round-headed, flat-headed, and fillister-headed screws. The difference between consecutive sizes is .01316 inch.

77. Special Gauges.—The gauges hitherto described are those in general use in the shop; but there are a great many special gauges of different forms, made for duplicate work and to facilitate manufacturing.

INSTRUMENTS FOR MEASURING SPEED

78. Speed Indicator.—The speed indicator, shown in Fig. 49 (*a*), is an instrument used to determine either the number of revolutions made by a rotating body in a given time, or the surface speed of a body. It consists of a spindle *a* that is free to turn easily in the body *b* of the instrument, and that is geared to the graduated ring *c* in such a way that 100 turns of the spindle cause the ring to make exactly one complete revolution. The ring is subdivided into 100 equal parts, and is numbered both right-handed and left-handed, so that the indicator may be used on a body turning in either direction. Each division on the graduated ring thus represents one turn of the spindle. A disk *d* fits inside the ring and is marked with 50 notches evenly spaced. The finger *e* is a spring that is screwed fast to the body *b* and that prevents the disk *d* from turning. However, every time the ring *c* makes a complete turn, the pin *f* passes under the spring *e*, lifts it for an instant, and allows the disk to revolve freely with the ring. The disk is thus rotated through one division at each complete turn of the ring, and each division on the disk represents 100 revolutions of the spindle *a*.

79. To use the speed indicator, shown in Fig. 49 (*a*), one of the tips illustrated in (*b*) or (*c*) is slipped over the end of the spindle *a*. If the shaft whose speed is to be found has a conical hole in the end, the tip shown in (*b*) is used; if the shaft is pointed, the tip in (*c*) is employed, and the end of the shaft then fits in a hole in the end of the tip. The ends of these tips are

made of rubber, so that there will be no slipping when they are pressed against the shaft. The ring c is next set to zero, which may be done by turning the spindle until the pin f comes against the spring e. The disk d may be set to zero by lifting the spring e and turning the disk until the pin g comes opposite the end of the spring. The indicator is held by the handle h, and a watch is taken in the other hand. At an observed time, the tip on the spindle a is pressed against the end of the rotating shaft and is held there for a minute, at the end of which time it is sharply withdrawn. The number of revolutions recorded on the ring, or on the disk and the ring, is the number of revolutions per minute of the shaft. If the indicator is held against the shaft only half a minute, the reading must be doubled in order to find the number of revolutions per minute.

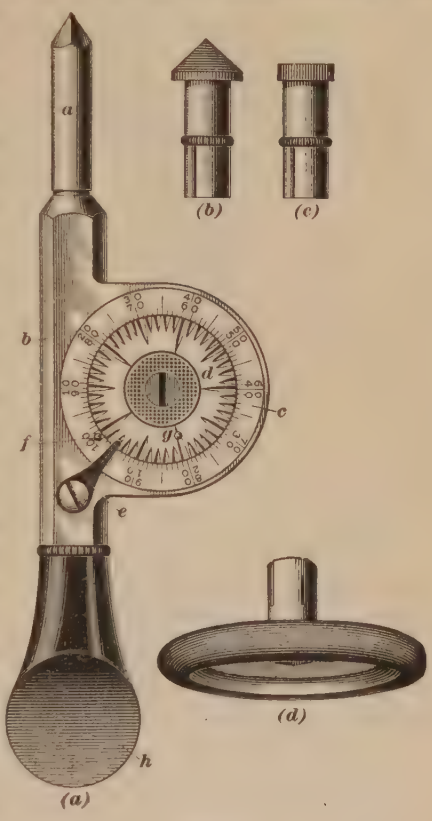


FIG. 49

80. If the spindle of the speed indicator, Fig. 49 (*a*), is fitted with the rubber-faced attachment shown in (*d*), it may then be used to find the speed, in feet per minute, at which the surface of a piece of work is moving. The rubber-faced wheel is slipped over the spindle in the same way as the tips shown in (*b*) and (*c*), and the indicator is set to zero, as already explained. The wheel is then pressed against the face of the work whose surface speed is to

be found, and is held there for an observed time, as, for example, one minute. In doing this the spindle *a* must be held parallel to the face of the work, and the time must be carefully noted. The wheel is of such size that every revolution represents a movement of 6 inches, or $\frac{1}{2}$ foot, of the surface of the work. Consequently, the total reading of the indicator, in revolutions per minute, is divided by 2, and the result is the speed of the surface of the work, in feet per minute.

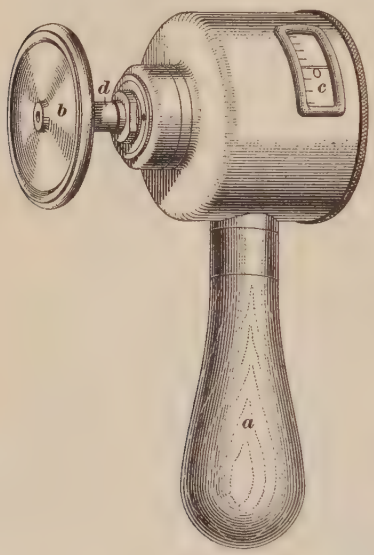


FIG. 50

81. Cut Meter.—The cut meter, illustrated in Fig. 50, is used to measure the surface speed of a body, in feet per minute, without either using a watch to time the operation or making calculations. The instrument is grasped by the handle *a* and the wheel *b* is held against the face of the work whose surface speed is to be found. The surface speed, in feet per minute, may then be read directly from the graduated scale *c*. It is necessary to hold the instrument in such a position that the shaft *d* is parallel to the face of the work.

INSTRUMENTS FOR MEASURING HARDNESS

82. Principle of Scleroscope.—The scleroscope, illustrated in Fig. 51 (*a*) and (*b*), is an instrument for measuring the hardness of materials, particularly of metals. The hardness is determined by dropping a small diamond-faced hammer from a fixed height on the piece to be tested, and observing the height to which the hammer rebounds. The harder the body tested, the higher will be the rebound of the hammer. The height

of the rebound is noted on a vertical scale divided into 140 equal parts, called *degrees of hardness*, and the number of the division to which the hammer rises on the rebound denotes the degree of hardness. This scale is purely arbitrary, so that the

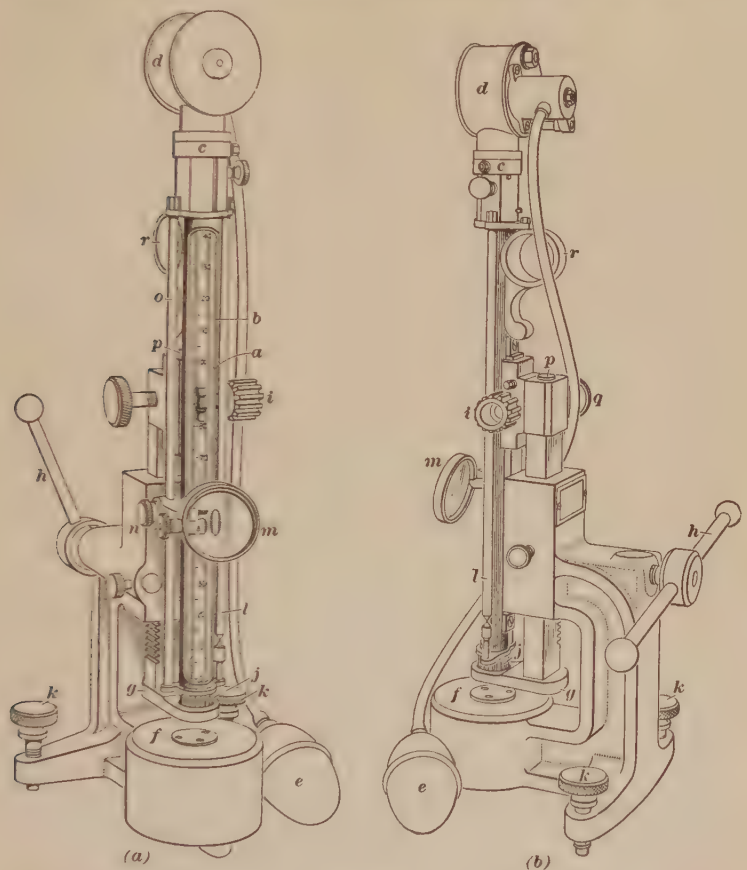


FIG. 51

various hardnesses determined by the instrument are only relative. Metals that can be machined have less than 50 degrees of hardness. The values for some of the common forms of metal are as follows: Gray cast iron, 25 to 50; annealed tool steel, 30 to 35; annealed high-speed steel, 35 to 40; chilled cast

iron, 50 to 80; cutting tools, 75 to 110; brass castings, 7 to 25; soft brass, 9 to 10; and hard brass, 45.

83. Operation of Scleroscope.—Front and side views of the Shore scleroscope are shown in Fig. 51 (*a*) and (*b*). The diamond-faced hammer *a* is allowed to fall inside the vertical glass tube *b*, at the back of which is the graduated hardness scale. The hammer is held by a pair of hooks contained inside the casing *c*, and the hooks are connected with valves inside the casing *d*. When the valves are moved by air pressure, caused by pressing the rubber bulb *e*, the hooks are forced to release the hammer, and it falls. It may be returned to its original position by squeezing the bulb a second time. The piece of work to be tested is placed on the base *f* and is firmly held down by the clamp *g*, which may be raised or lowered by turning the arm *h*. Pressure should always be put on this arm when a test is being made, so that the work will be held firmly. The glass tube is held in a barrel that may be raised or lowered by turning the knob *i*. The lower end *j* of this barrel projects through a hole in the clamp *g* and touches the work when a test is being made. The glass tube must be set vertically, which may be done by adjusting the screws *k* in the base; the plumb-rod *l* will show when the instrument stands truly vertical.

84. The result of a scleroscope test is obtained by observing to what height the top of the hammer rebounds, as indicated on the scale; consequently, the top of the hammer should be watched closely. It may be necessary to try several times before an accurate reading can be obtained. In such cases, the first few tests will show the approximate height, and will indicate to the observer the point at which he should look. It is advisable to fix the eyes on a point a trifle lower than the height of the first rebound, as it is easier to note the next reading in this way than by looking at a higher point. Under no circumstances should the hammer be allowed to fall twice on the same spot, for readings thus obtained are not accurate. If exceedingly close readings are desired, the magnifying lens *m*, Fig. 51, should be used; it may be adjusted to the necessary point by loosening the screw *n* and moving the bracket along the rod *o*. The

barrel of the scleroscope is fixed on the post p and is held by the screw q. When desired, the barrel may be removed and carried to the piece of material to be tested, being held in the hand by the grip ring r; or it may be fixed to a swinging arm, so as to be brought over the work. The latter arrangement is very convenient when a large number of similar pieces are to be tested.

INSTRUMENTS FOR MEASURING TEMPERATURE

85. Fahrenheit Thermometer.—The thermometer is an instrument that is used to measure the temperatures of various substances. A common form, known as a Fahrenheit thermometer, is illustrated in Fig. 52. It consists of a glass tube of small inside diameter having a bulb at its lower end and sealed at the top. The bulb is filled with mercury, or quick-silver, which possesses the property of expanding when heated. Thus, when the thermometer is placed near a heated body, or in contact with such a body, the mercury expands and rises inside the glass tube; when the body is cooled, the mercury contracts and moves downwards in the tube.

FIG. 52

86. A graduated scale is formed on the back of the glass tube. The height at which the mercury stands when the thermometer is placed in melting snow and ice is the *freezing point*, and is marked 32; the point to which the mercury rises when the instrument is placed in boiling water is the *boiling point*, and is marked 212. The space between these marks is divided into 180 equal parts, called degrees, and 32 of these divisions are laid off below the freezing point, thus locating the zero point. The height on the scale at which the mercury comes to rest when the thermometer is applied to a body, is the Fahrenheit temperature of the body, in degrees, and is usually abbreviated °F. Thus, a temperature of 62° F. means a temperature of 62 degrees indicated on the scale of a Fahrenheit thermometer. The graduations may be extended above the boiling point and below the zero as far as may be desired. In the

illustration, only every other degree mark is shown; that is, each division represents 2° of temperature

87. Centigrade Thermometer.—In scientific work the centigrade thermometer is used very largely. In principle and construction it is like the Fahrenheit thermometer; but its graduated scale is different. On the centigrade thermometer, the freezing point of water is marked 0 and the boiling point is marked 100, and the space between these two marks is divided into 100 equal parts, or degrees. Consequently, a degree on the centigrade scale is larger than a degree on the Fahrenheit scale. Temperatures on the centigrade scale are usually abbreviated °C.; thus, a temperature of 24° C. indicates 24 degrees on the centigrade thermometer.

88. Use of Pyrometer.—A thermometer using mercury cannot be used to measure very high temperatures, such as those of furnaces, molten metal, and so on, because the mercury would boil and become a gas, and the glass tube would melt. To measure high temperatures it is necessary to use a pyrometer, which is an instrument specially designed for high-temperature work. Pyrometers are of many kinds and act on different principles. It would be impossible to describe each of the various types; consequently, only a few forms will be illustrated here.

89. Le Chatelier Pyrometer.—An outside view and a sectional view of a Le Chatelier pyrometer are given in Fig. 53 (*a*) and (*b*). The instrument consists of a pipe *a*, at one end of which is a clamp *b* holding a hollow fire-clay cone *c* that is capable of resisting great heat. Inside the cone are two wires *d* and *e*, one of platinum and the other of an alloy of platinum and rhodium. These two wires are joined at *f*, in the tip of the cone, and their ends are carried back through the pipe *a* to a box *g* at the other end, where they are firmly fastened to the posts *h* and *i*. Two wooden handles *j* and *k* are provided, the first being fixed to the box *g* and the other being loose on the pipe, so that it can be moved nearer to or farther from the clamp *b*. A metal screen *l*, lined on the inside with asbestos, is attached to the handle *k* to protect the hand of the workman from the heat when the pyrometer is being used. From the posts *h* and *i*

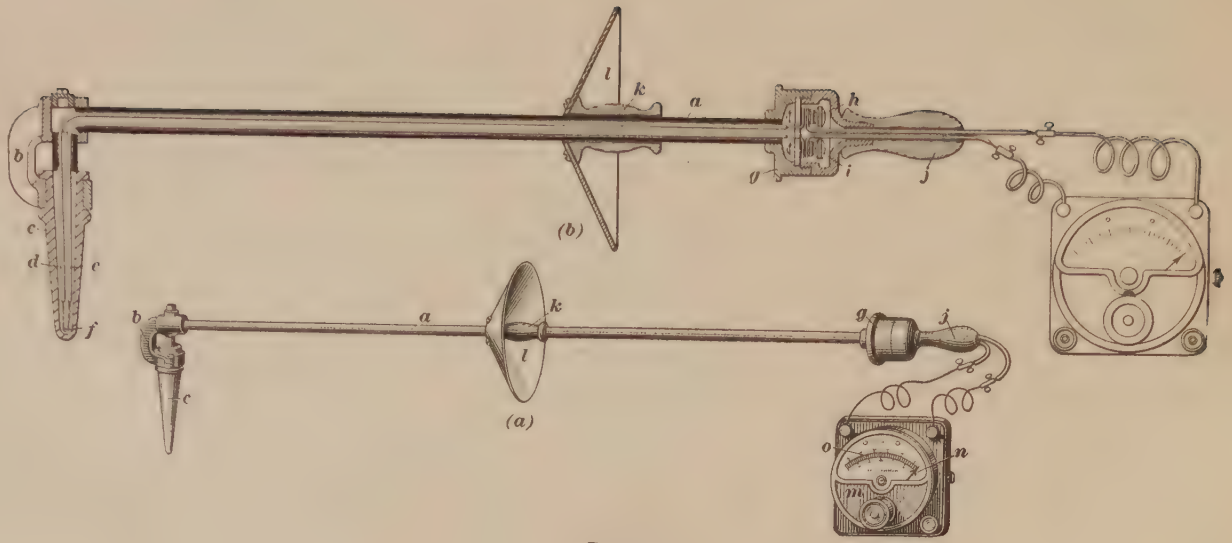


FIG. 53

separate wires are led out through the handle j, and are connected to an electrical instrument m, called a galvanometer, having a pointer n that moves over a graduated scale o.

90. The pyrometer shown in Fig. 53 acts on the principle that when the joined ends of the two wires d and e are heated, an electric current is set up in the wires, and the higher the temperature, the stronger is the current. Thus, if the pyrometer is taken by the handles and the fire-clay tip c is plunged into a ladle of molten metal whose temperature is to be found, the hot metal will heat the joint f and a current will be set up in the wires. This current will cause the pointer of the galvanometer to swing over the scale, its stopping point depending on the strength of the current. The scale is usually graduated to show the temperature, although it may also indicate the strength of the current. The reading at which the pointer comes to rest, therefore, indicates the temperature of the molten metal. The galvanometer may be located at any convenient point, either near or far away from the pyrometer. The connecting wires must, of course, be of suitable lengths.

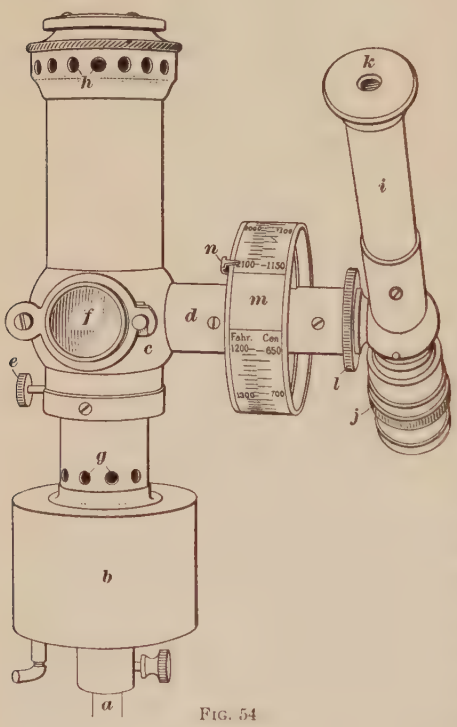


FIG. 54

91. Shore Pyroscope.—The Shore pyroscope, shown in Fig. 54, is used to determine the temperature of heated metal by

comparing the color of the hot piece with the reflected light of a kerosene burner. The instrument is mounted on a rod *a* that is fixed in a three-legged base, not shown. The tank *b* contains kerosene, and inside the casing *c* is a burner, on a level with the tube *d*. The wick is adjusted by the button *e* and may be lighted by opening the glass door *f*. The air for the burner enters the holes *g*, and the gases escape through the holes *h* at the top of the chimney. When the burner shows a flame about $\frac{3}{4}$ inch high, the telescope *i* is swung so as to point directly at the piece of metal whose temperature is to be found, and the nurled ring *j* is turned until the focus is correct and the work is clearly visible through the eyepiece *k*. The work may have a color ranging from a dull red to a brilliant white, depending on the degree to which it is heated.

92. Inside the telescope, opposite the end of the tube *d*, Fig. 54, is a small round reflector on which the light of the kerosene burner falls and is reflected toward the eyepiece, so that the eye of the observer sees the light from the hot work and that from the reflector. The nurled ring *l* is now turned, which revolves a colored diaphragm inside the tube *d*, and thus alters the amount of light that falls on the small reflector from the oil burner. As the ring *l* is turned, the drum *m* is turned with it, and the graduations of the temperature scales marked on the drum pass under the end of the stationary pointer *n*. When a point is reached at which the color of the heated work and the color of the light reflected from the small reflector are the same, the reading on the graduated scale, opposite the pointer *n* is taken, this being the temperature of the work. There are two scales on the drum, one denoting the temperature in Fahrenheit degrees, and the other the temperature in centigrade degrees.

PRECISION MEASURING INSTRUMENTS

KINDS OF INSTRUMENTS

CLASSIFICATION

1. For the ordinary work of the machinist, patternmaker, foundryman, or blacksmith, the steel or wooden rules described in *Measuring Instruments* are accurate enough and measurements that cannot be made with the rules directly are transferred by the calipers and dividers there described. For the finer measurements necessary in machine-shop work and for toolmaking or gauge making, very much finer measurements must be made than those that are possible with the ordinary rule or calipers. Such measurements are called **precision measurements,** and the instruments used in making them are commonly called **precision measuring instruments.**

2. Precision measuring instruments are classified as follows: *Vernier instruments, micrometers, vernier micrometers, measuring machines, instruments for differential measurements, indicators, dial calipers,* and *thickness gauges.*

Precision measurements are generally read by shop men in thousandths and fractions of thousandths of an inch. Thus, .0001 inch would be read $\frac{1}{1}$ of a thousandth of an inch; similarly, .00005 inch would be read $\frac{5}{10}$, or $\frac{1}{2}$, of a thousandth of an inch; .0783 inch would be read $78\frac{3}{1}$ thousandths of an inch; .5432 inch would be read $543\frac{2}{1}$ thousandths of an inch, etc.

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VERNIER INSTRUMENTS

GENERAL INFORMATION

3. A **vernier instrument** is a precision measuring instrument in which measurements are made by means of the vernier scale. The **vernier,** or **vernier scale,** is a scale which, by means of its graduation, makes possible fine subdivisions of dimensions without placing the graduation lines so close together that they will prove confusing. The scale to be subdivided by means of the vernier scale is called the **true scale.** A vernier is used on a measuring instrument for measuring shorter lengths than those represented by the smallest divisions of the true scale. The vernier consists of a short scale arranged to slide along the true scale. By its application to shop measuring instruments it is possible to measure lengths as short as

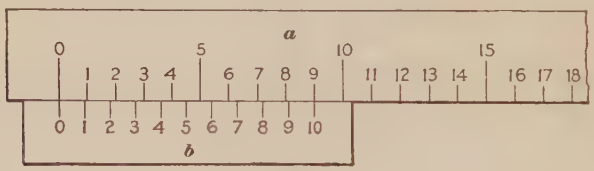

FIG. 1

$\frac{1}{10000}$ inch, the graduations on both the true and vernier scales being large enough to be easily read.

The lines of a vernier are numbered from the zero and are read from that point; thus, the line that has *0* written below it is called the *zero line*, the line next to it at the end of the first space is called the *first line*, the line at the end of the second space is called the *second line*, etc.

In the discussion that follows, unless otherwise stated, a division of the true scale, in order to simplify the text, will be spoken of as *a division*.

4. Principle of the Vernier.—In Fig. 1, let the vernier scale *b* have 10 divisions, the sum of which is equal in length to 9 divisions on the true scale *a*. One division of the vernier

scale will then be equal to $\frac{9}{10}$ division of the true scale. If the zeros on the two scales coincide, the line numbered *1* on the vernier falls $\frac{1}{10}$ division of the true scale short of coinciding with the line numbered *1* on the true scale; line *2* of the vernier falls short $\frac{2}{10}$ division of the true scale of coinciding with line *2* of the true scale; line *3* falls $\frac{3}{10}$ division of the true scale short of coinciding with line *3* of the true scale; and so on. In like manner each successive line will fall short $\frac{1}{10}$ division more than the preceding line.

The number on the vernier scale indicates the number of tenths of a division of the true scale that that line falls short of coinciding with the line having the same number on the true scale.

5. Since, when the zeros coincide, the distance between the lines numbered *3* of each scale is $\frac{3}{10}$ division of the true scale,

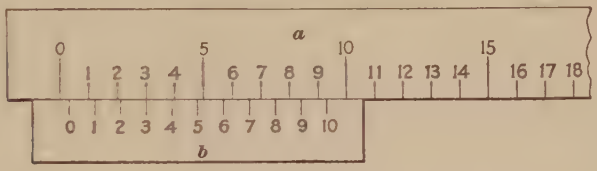

FIG. 2

if the vernier scale is moved forwards, as in Fig. 2, until line *3* on it coincides with line *3* on the true scale, the zero of the vernier scale will then be $\frac{3}{10}$ division away from the zero of the true scale, or the distance between the two zeros will be $\frac{3}{10}$ division. Also, in the same manner, if line *7* of the vernier is made to coincide with line *7* of the true scale, the distance between the two zeros will be $\frac{7}{10}$ division of the true scale; if the two *9*'s coincide, the distance between the two zeros will be $\frac{9}{10}$ division of the true scale; if the two *10*'s coincide, the zero of the vernier scale will also coincide with line *1* of the true scale. Clearly, then, when the zero of the vernier is between zero and line *1* of the true scale, the number of tenths of a division of the true scale between the two zeros can be told at once by finding the number of the line of the vernier scale that coincides with one of the lines of the true scale.

6. The vernier and true scales are often made, as illustrated in Fig. 3, so that 25 divisions of the vernier scale are equal to 24 divisions of the true scale. In this case 1 division of the vernier scale is equal to $\frac{24}{25}$ division of the true scale. Should the zero of the vernier scale coincide with any line of the true scale, line *1* on the vernier scale would fall short $\frac{1}{25}$ division of coinciding with the first line on the true scale to the right of the zero of the vernier scale. Similarly, line *24* on the vernier scale would fall short $\frac{24}{25}$ division of coinciding with the twenty-fourth line on the true scale to the right of the zero line of the vernier scale.

7. If the vernier scale is now moved forwards, as in Fig. 3, until the line numbered *10* on the vernier coincides with a line on the true scale, the zero of the vernier scale will then be

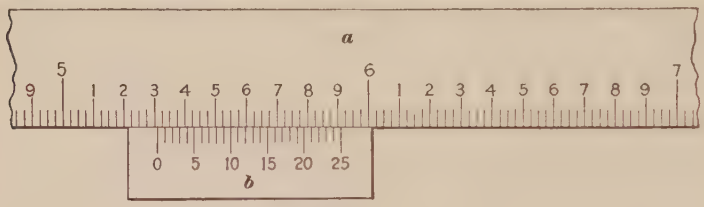

FIG. 3

$\frac{10}{25}$ division from the first line to the left of it on the true scale. When the zero of the vernier is between any two lines on the true scale, the number of twenty-fifths of a division of the true scale between the zero of the vernier scale and the line immediately to the left of it on the true scale, can be told at once by finding the number of the line of the vernier scale that coincides with one of the lines of the true scale.

8. The vernier scale on some measuring instruments is also made with 20 divisions and with 24 divisions. The vernier readings will then be in twentieths or twenty-fourths, respectively, of the divisions to which the true scale is graduated.

9. In the cases illustrated in Figs. 1 and 2, let each division of the true scale be $\frac{1}{10}$ inch. By means of the vernier scale, readings may then be made to $\frac{1}{10}$ division of the true scale or $\frac{1}{10}$ of $\frac{1}{10}$, or $\frac{1}{100}$ inch. Should each division of the true scale represent

$\frac{1}{10}\frac{1}{00}$ inch, which occurs in instruments to be described later, readings could be made to $\frac{1}{10}$ division of the true scale or $\frac{1}{10}$ of $\frac{1}{1000}$, or $\frac{1}{10000}$ inch.

If, in the case illustrated in Fig. 3, each division of the true scale is $\frac{1}{40}$ inch, which occurs in instruments to be described later, readings may be made to $\frac{1}{25}$ division of the true scale, or $\frac{1}{25}$ of $\frac{1}{40}$, or $\frac{1}{1000}$ inch.

If each division of the true scale represents $\frac{1}{50}$ inch and the vernier is divided into 20 divisions, readings may be made to $\frac{1}{20}$ division of the true scale, or $\frac{1}{20}$ of $\frac{1}{50}$, or $\frac{1}{1000}$ inch.

10. If each division of the true scale represents 1 degree, and the vernier is divided into 24 divisions, readings may be made to $\frac{1}{24}$ division of the true scale, or $\frac{1}{24}$ degree, or $\frac{1}{24}$ of 60 minutes, or $2\frac{1}{2}$ minutes.

The vernier scale need not be confined to reading hundredths, thousandths, or ten-thousandths, but may read to any subdivision required for the work.

11. It will be observed that in every case so far considered, the lengths of the divisions on the vernier scales are less than the lengths of the divisions on the true scale. Vernier instruments in which this rule prevails are known as **direct-vernier instruments.** All vernier instruments considered in this Section are direct.

The number of divisions on the true scale equal to the total length of the vernier divisions are usually equal to the number of divisions on the vernier scale less one. This is not always the case, as will be seen later, when studying the vernier protractor. It will, however, be understood to be the case in interpreting the rules of this Section.

12. Subdivisions Obtainable by a Vernier.—The number of subdivisions obtainable by a vernier may be found by the application of one of the following rules:

Rule I.—*To find the number of subdivisions of an inch which may be measured by the vernier instrument, multiply the number of divisions on 1 inch of the true scale by the number of divisions on the vernier scale.*

EXAMPLE 1.—In a vernier each inch of the true scale is divided into 16 parts. The vernier scale contains 8 divisions. What subdivision of the inch can be obtained?

SOLUTION.—Applying the rule just given, the number of parts into which the inch is divided is equal to $16 \times 8 = 128$. Ans.

EXAMPLE 2.—The unit of measurement on a true scale is not subdivided, while the vernier scale has 12 divisions or spaces. What subdivisions of the unit can be obtained?

SOLUTION.—Since the unit of measurement is not subdivided, the number of parts into which it may be conceived to be divided is 1. Then, by the rule just given, the number of subdivisions is $1 \times 12 = 12$. Ans.

Rule II.—*To find the smallest subdivision of a degree, expressed in minutes, which may be measured by a vernier, divide sixty by the number of subdivisions on the vernier.*

EXAMPLE 3.—The true scale of a protractor is divided into degrees, and the vernier scale is divided into 24 divisions, whose total length is equal to 23 degree divisions on the true scale. How close may readings be made with this instrument?

SOLUTION.—By the rule, the smallest subdivision of a degree, expressed in minutes, which may be measured by the vernier is $\frac{60}{24}$, or $2\frac{1}{2}$. Hence, the instrument will read as close as $2\frac{1}{2}$ minutes. Ans.

13. Reading the Vernier.—Vernier instruments may be read by applying the following rules:

Rule I.—*The vernier must always read from its zero point onwards in the same direction as the numbers of the true scale increase.*

The reading of the instrument will be the reading of the true scale, as indicated by the zero of the vernier scale, plus the reading of the vernier.

Rule II.—*To read a vernier instrument, proceed as follows: Observe the location of the zero point of the vernier scale, to obtain the number of whole divisions it is from the zero line of the true scale. From the zero point of the vernier scale, advance until a line is found on it that coincides with a line of the true scale. The number of spaces included between this line on the vernier scale and the zero point of the vernier scale is the number of the subdivisions obtained by the vernier that is to be added to the number of whole divisions previously found on the true scale.*

14. The following rule may be used for reading any vernier instrument designed for linear measurements, and measuring thousandths of an inch.

Rule.—*To read a vernier instrument designed for linear measurements in thousandths of an inch, count the number of whole inches between the zero of the true scale and the zero of the vernier scale. Count the number of tenths-of-an-inch spaces between the last whole-inch mark and the zero line of the vernier scale. This is the first decimal figure of the reading. Observe how many subdivisions of the tenth part of the inch are between the last tenth-of-an-inch mark on the true scale and the zero of the vernier scale. Express the value of these subdivisions in thousandths of an inch and add it to the value already found. Next count the number of spaces between the zero of the vernier scale and the line that coincides with one of the true scale; this number, if the instrument reads to thousandths, is the number of thousandths to be added to the true-scale reading for the complete reading.*

Thus, if the line at the end of the third space is the coinciding one, add 3 one-thousandths to the true-scale reading;

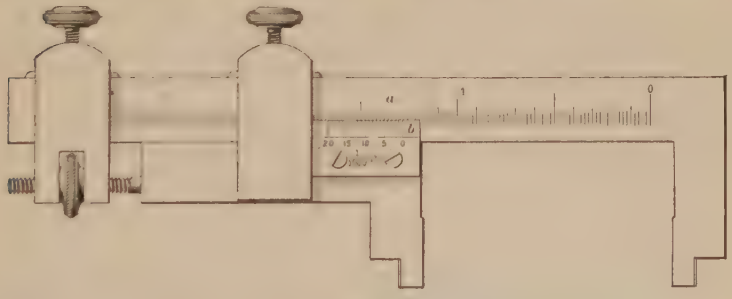

FIG. 4

if the line at the end of the ninth space coincides with one of the true scale, add 9 one-thousandths, etc. With a little practice the reading can be taken very rapidly by this rule, since the calculations are so simple that they can be performed mentally.

EXAMPLE.—What is the reading of the vernier caliper square shown in Fig. 4?

SOLUTION.—The number of whole inches is 1. Hence, write 1 as the integral part of the reading. There are two $\frac{1}{10}$-inch spaces between the graduation mark denoting 1 in. and the zero line of the vernier scale *b*. Hence, write 2 as the first decimal figure of the reading, giving 1.2 in. By inspection of the caliper square, it is seen that there are 4 subdivisions of the tenth part of an inch between the last $\frac{1}{10}$-in. mark and the zero line of the vernier scale. Now, in this case, each space represents $\frac{1}{50}$ in., or, expressed in thousandths, .020 in. Hence, 4 spaces represent $.02 \times 4 = .08$ in. Adding this to the previous reading, the reading of the true scale *a* is $1.2 + .08 = 1.28$ in. Inspection shows that the line at the end of the seventh space of the vernier scale coincides with a line on the true scale. Hence, as the instrument reads to thousandths, 7 one-thousandths should be added to the true-scale reading, giving $1.280 + .007$, or 1.287 in., as the complete reading. Ans.

Vernier readings may usually be made with the naked eye. However, should the graduations be close together, a magnifying glass is sometimes used.

APPLICATIONS OF THE VERNIER

15. Vernier Caliper Square.—The vernier is most frequently applied to caliper squares in order to obtain fine

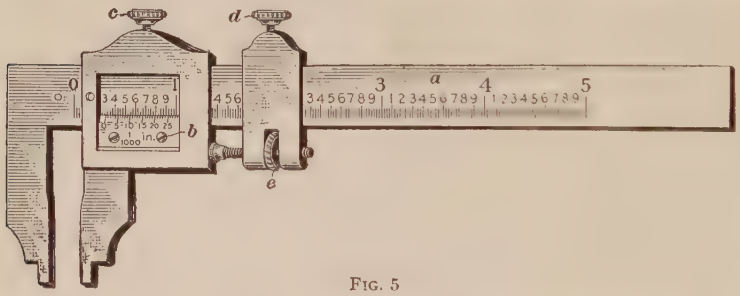

FIG. 5

measurements. The vernier caliper square, illustrated in Fig. 5, as used in the United States, is commonly made to read to thousandths of an inch. Fig. 6 shows the vernier scale and a portion of the instrument enlarged. The true scale *a*, which reads to fortieths of an inch, is engraved on the beam; while the vernier scale *b*, which has 25 divisions, is attached to the sliding head. For convenience in manufacturing, the vernier scale is in this case engraved on a separate plate, which is then fastened by small screws, as shown.

When adjusting the instrument, the screws c and d, Fig. 5, are loosened and the sliding head is moved approximately to the dimension to be measured. The screw d is then tightened,

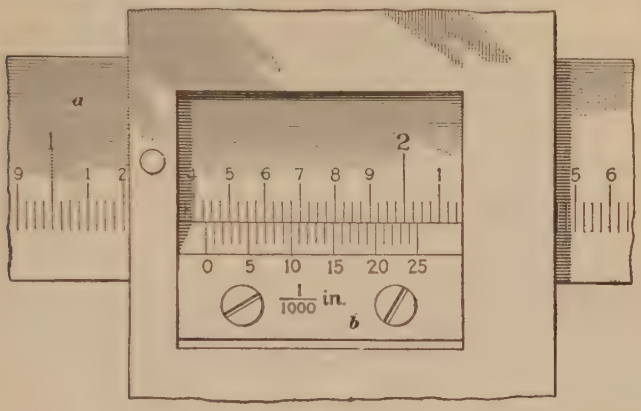

FIG. 6

and fine adjustment made by the nut e. The screw c is now tightened.

Applying the rule of Art. **14**, the reading of the instrument in the position shown in Fig. 6 is:

	INCHES
Whole number of inch	1.000
Additional tenths of inch	.400
Additional subdivision of tenths-of-an-inch space is 1, or $\frac{1}{4}$ of $\frac{1}{10}$, or $\frac{1}{40}$, or	.025
Vernier reading	.010
	1.435

16. It is to be observed that the reading obtained with this instrument is the measurement between the jaws; that is, an outside measurement. For inside measurements, add to the reading an amount equal to the total width of the jaws when closed.

17. The back side of the square, shown in Fig. 7, is graduated to read to sixty-fourths of an inch. By means of the lines marked *in* and *out* on the sliding head, the distance between

them being equal to that across the points of the closed jaws, inside and outside measurements may be made directly.

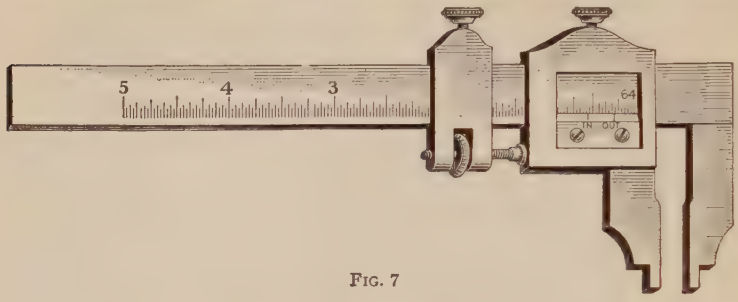

FIG. 7

18. Vernier caliper squares are usually made in 3-inch, 6-inch, 12-inch, and 24-inch sizes. A 3-inch size will make measurements from zero to 3 inches; a 6-inch size from zero to 5 inches, etc.

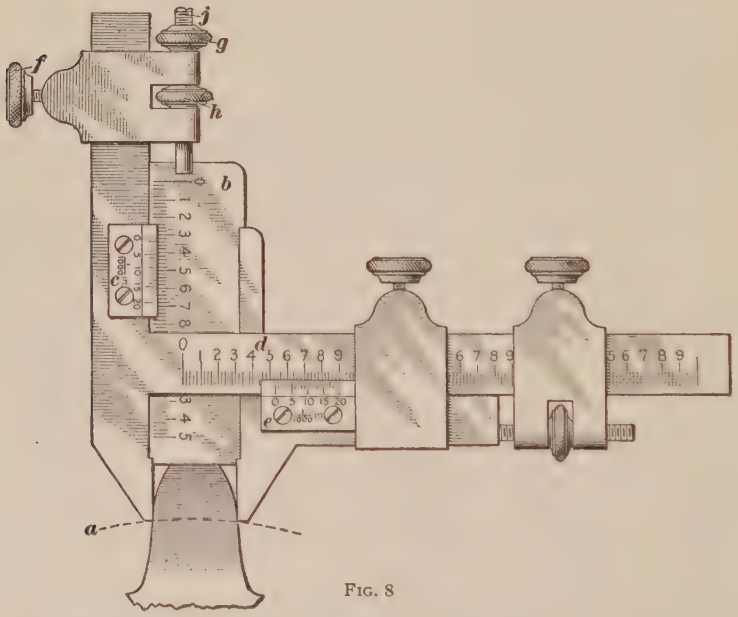

FIG. 8

19. Gear-Tooth Vernier Caliper.—The gear-tooth vernier caliper illustrated in Fig. 8 is designed to measure accurately

the thickness of a gear-tooth on the pitch circle. The instrument is first set to the correct distance from the top of the tooth to the pitch circle, which is represented in the figure by the dotted line *a*, by means of the tongue *b* and the vernier *c*. The thickness of the tooth is then measured by means of the scale *d* and the vernier *e*. Both verniers read to thousandths of an inch.

The horizontal head of this instrument is adjusted precisely as the sliding head of the caliper square just described. When

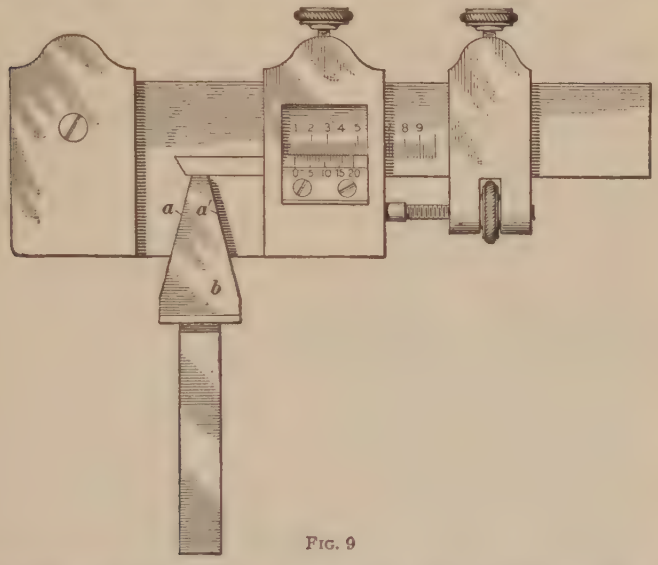

FIG. 9

adjusting the vertical head, the screw *f* and the nut *g* are loosened. The instrument is then set approximately to the desired dimension. Finer adjustment is made by means of the nut *h*, the setting being locked by the nut *g*. When using the instrument care should be taken that the recess in the tongue *b* bears firmly against the end of the screw *j*.

20. Vernier Thread-Tool Caliper.—The vernier thread-tool caliper shown in Fig. 9 is designed to gauge thread tools when grinding them. All widths of tool points up to about $\frac{6}{10}$ inch may be measured with this caliper, thus doing away

with separate gauges for grinding tools having different widths of point. The angle between the hardened jaws a and a' is 60° for United States standard threads, and 29° for the 29° standard threads. In use, the tool b is held against the jaw a and the jaw a' is then brought against the tool and the measurement made as with the ordinary vernier caliper. The vernier reads to thousandths of an inch.

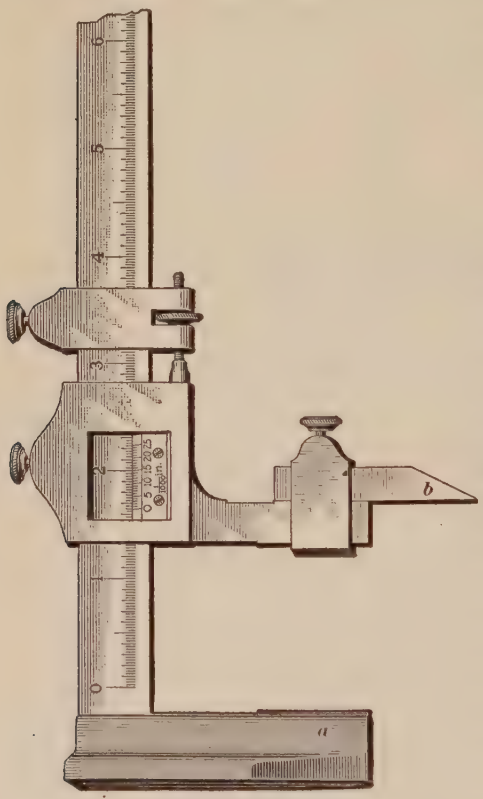

FIG. 10

21. Vernier Height Gauge. The vernier height gauge, illustrated in Fig. 10, is designed to measure heights accurately. It is used to obtain the heights of projections from a plane surface, to locate bushings in jigs, and to lay out work on vertical surfaces. The base a is made wide enough to allow the gauge to stand upright. The distance across the base and upper jaw when closed is 1 inch; hence, 1 inch must be added to the reading of the instrument to get the correct measurement. By the use of the extension piece b, it is possible to reach over projections in order to lay out or measure work as desired. The vernier reads to thousandths of an inch.

22. Vernier Depth Gauge.—The vernier depth gauge illustrated in Fig. 11 is a depth gauge with a vernier scale.

It reads to thousandths of an inch with the vernier scale, and to sixty-fourths of an inch with the scale on the opposite side.

23. Vernier Bevel Protractor.—Fig. 12 illustrates a bevel protractor with a vernier scale attached for the purpose of measuring subdivisions of the degree. Fig. 13 shows a portion of the disk, or true scale *a*, Fig. 12, and the vernier scale *b* enlarged. The vernier and true scales are designed so that 24 divisions of the vernier scale equal 23 degree divisions on the true scale. By rule II of Art. **12,** the smallest subdivision of the degree, expressed in minutes, obtainable is $\frac{60}{24}=2\frac{1}{2}$ minutes. In practice, however, it is not found desirable to work as close as $2\frac{1}{2}$ minutes, 5 minutes being sufficiently close. Every other division is therefore omitted on the vernier scale and the closest reading obtainable is 5 minutes.

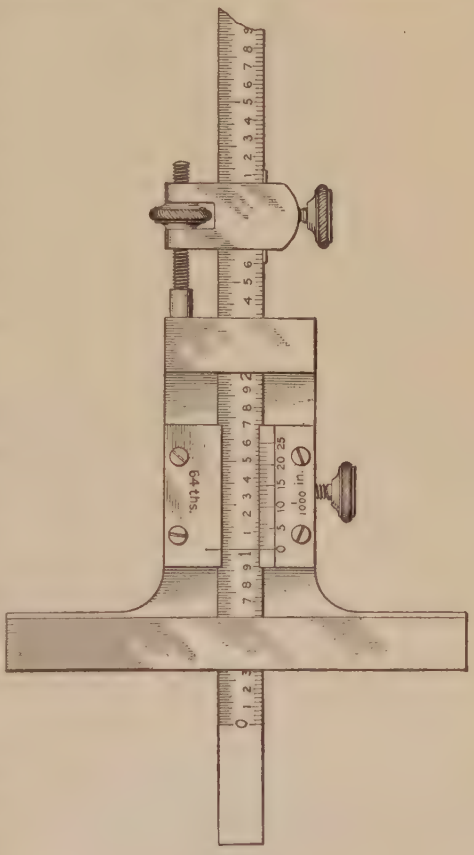

FIG. 11

24. The instrument could have been designed to read to 5 minutes by making 12 divisions on the vernier equal to 11 degree divisions on the true scale. The distance between the lines of the vernier would then be about half as large as that obtained by the design used.

By applying rule I of Art **13,** the numbers to the left of zero on the vernier scale *b*, Fig. 13, would be used to take the reading in the position shown and the numbers to the right of zero on

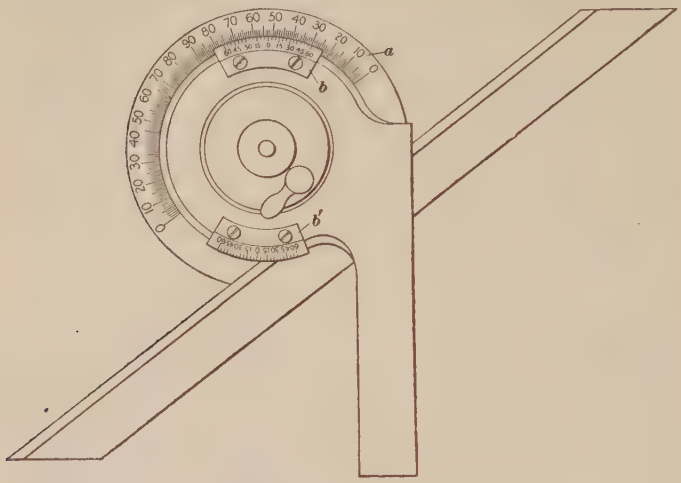

FIG. 12

the vernier scale would be used to take the reading when the vernier-scale zero corresponds with any position on the left half of the true scale *a*, Fig. 12. The vernier scale *b'* would be used

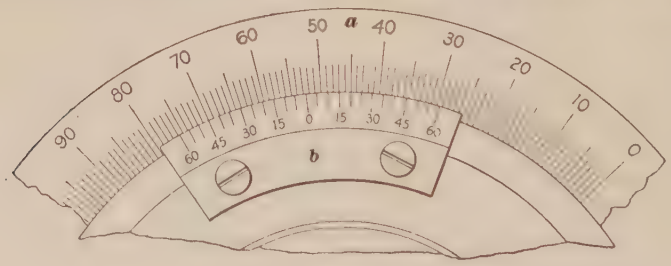

FIG. 13

similarly to *b* when its zero mark corresponds with some position of the true scale.

25. Reading Vernier Bevel Protractor.—It will be observed that in Fig. 13 the line at the end of the ninth space on the vernier is marked *45*, which represents the number of

minutes to be added to the degree reading. Should the vernier not be marked in this manner, the number of spaces from the zero of the vernier scale to a line coinciding with a line on the true scale multiplied by 5 will be the number of minutes to be added to the degree reading of the protractor.

The following rule will be found useful for reading protractors of the type described:

Rule.—*To read any vernier protractor, read off directly the number of whole degrees between the zero of the true scale and the zero of the vernier scale. Add to this reading the number of minutes shown by the number under that line of the vernier scale which coincides with a line of the true scale.*

EXAMPLE.—Read the vernier protractor shown in Fig. 13 to degrees and minutes.

SOLUTION.—There are 52 whole degrees between the zeros of the true scale and the vernier scale. The line numbered 45 of the vernier scale coincides with a line of the true scale. Hence, the reading of the protractor is 52° 45′. Ans.

26. Setting Vernier Protractor.—The operation of setting the protractor is the converse of that of reading it. For example, if it were required to set the instrument to 52° 45′, the operation would be as follows: Move the true scale to the right until the 52° mark is opposite the zero of the vernier; then, looking at the vernier scale, move the true scale carefully to the right until the line numbered *45* on the vernier scale coincides with a line of the true scale.

MICROMETERS

PRINCIPLE OF THE MICROMETER

27. A **micrometer** is a precision measuring instrument in which an accurate screw is used for determining the measurements. Micrometers are usually constructed to read to thousandths of an inch for ordinary use and to $\frac{1}{100}$ millimeter for scientific measurements. The principle and method of using are identical in both systems.

28. Micrometer Screw.—The screws used on micrometers have right-handed threads; that is, the screw moves forward when turned to the right. In order to study the principle of the micrometer, the simple outside micrometer caliper illustrated in Fig. 14 may be considered. In order to determine easily through what part of a revolution the screw has been turned, the *micrometer screw a* is supplied with a *thimble b*, which is graduated on one edge. The cut shows the screw uncovered, for the purpose of more clearly illustrating the principle. Micrometers of recent manufacture have the screw covered, in order to protect it from wear. A line *c* engraved lengthwise on the *barrel d*, which is attached to the frame, serves as a zero line from which to read the part of a revolution through which the micrometer screw has been turned. In order to adapt the micrometer screw for end measurements, an *anvil e* is provided, the surface of which is a plane surface parallel to that on the end of the screw. The anvil is so adjusted by means of the screw *f* that when the end of the micrometer screw is in contact with it, the end of the thimble will coincide with the zero line on the barrel and the zero line on the thimble will coincide with the line *c* on the barrel.

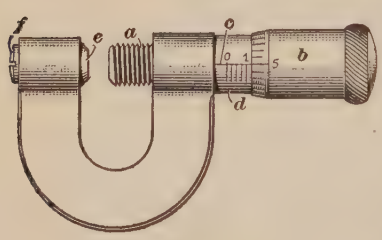

FIG. 14

29. The advance in one turn, which the thread makes, in a line parallel to the axis of the screw is called the **lead.** If a screw of known lead is fitted in a fixed nut so that the screw can be turned while the nut remains stationary, and the screw is turned one complete revolution, it will advance in the direction of its axis a distance exactly equal to the lead of the thread. But if it is turned exactly one-half of a complete revolution, it will advance a distance equal to one-half the lead of the thread. Following this line of reasoning, it is seen that the amount the screw advances in the direction of its axis in a fraction of one revolution is equal to the product of the lead and the fraction

expressing the part of the revolution through which the screw has been turned.

30. Assume that the micrometer screw has 40 right-handed threads to the inch, and a lead of $\frac{1}{40}$ inch. Then, if the screw is turned $\frac{1}{25}$ of a complete revolution, the amount advanced will be $\frac{1}{40} \times \frac{1}{25} = \frac{1}{1000}$ inch. It is to be observed that the thimble *b* and the screw *a*, Fig. 14, are rigidly connected. Hence, if there are 25 equal graduations on the circumference of the thimble *b*, the screw *a* will advance lengthwise $\frac{1}{1000}$ inch when the thimble *b* is turned 1 division to the right. Every 5 divisions of the thimble are marked *0*, *5*, *10*, *15*, *20*, and are read thousandths. One inch of the lengthwise line *c* is divided into 40 equal divisions, every division being equal to $\frac{1}{40}$ or .025 inch, and every fourth division representing tenths of an inch. Every fourth division of the line *c* is marked as follows and read tenths: *0*, *1*, *2*, *3*, *4*, *5*, *6*, *7*, *8*, *9*.

31. Reading the Micrometer.—Practically all micrometers for measuring thousandths of an inch use a screw having forty threads per inch, and have the thimble graduated so that each space is equal to one twenty-fifth of a revolution. Hence, they read directly to thousandths of an inch. Assuming that the micrometer screw and the anvil are in contact, let the micrometer screw be turned back until the graduations on the thimble show, by reference to the zero line on the barrel, that it has made seven twenty-fifths of a revolution. Then, the opening between the end of the micrometer screw and the anvil will, if the lead of the thread is $\frac{1}{40}$ inch, be $\frac{7}{1000}$ inch. Now, in order to measure sizes in excess of $\frac{1}{40}$ inch, or .025 inch, the screw must make more than one turn. When the micrometer screw is turned one complete revolution, the second graduation line on the barrel will be even with the end of the thimble, so that the thimble is 1 space from the beginning of the graduation on the barrel. If the micrometer screw is turned through another revolution, there will be 2 spaces visible; hence, the number of spaces shows how many complete turns the micrometer screw has made. As each space represents $\frac{1}{40}$ inch, or $\frac{25}{1000}$ inch, to find the distance represented by an unknown number of whole turns,

count the number of spaces and multiply by .025. Then read off the fractional part of a turn and add it to the first value.

32. Hence, to read a micrometer measuring thousandths multiply the number of whole spaces visible on the barrel by .025. Add the number of spaces between the zero line of the thimble and the zero line on the barrel multiplied by .001.

As each graduation on the barrel equals .025 inch, four of these spaces must equal $4 \times .025 = .1$ inch. Therefore, every fourth line of the graduations stands for .1 inch, and the figures *0*, *1*, *2*, *3*, etc. are stamped on the barrel to indicate these tenth-inch graduations. They stand for .0, .1, .2, .3, etc. inch. As each space represents a distance of $\frac{25}{1000}$, or .025 inch, the line at the end of the first space denotes a .025-inch opening; the line at the end of the second space, .050 inch; the line at the end of the third space, .075 inch.

33. In order to save multiplication, the following rule may be used:

Rule.—*To read a micrometer measuring thousandths of an inch, look for the last figure that is exposed on the barrel. This is the first decimal figure of the dimension. Count the number of whole spaces beyond the last figure and between it and the end of the thimble. For one space, annex 25; for two spaces, annex 50; and for three spaces annex 75 to the first figure. Mentally add the number of spaces, expressed in thousandths of an inch, between the zero line of the thimble and the zero line on the barrel, counting from the zero line of the thimble forwards.*

EXAMPLE.—What is the reading of the micrometer shown in Fig. 14?

SOLUTION.—The last figure that is exposed is 1. There is one whole space between this figure and the end of the thimble, but the line representing it cannot be distinguished in the figure, as it is so near the end of the thimble. Since there is one whole space between this figure and the end of the thimble, annex 25, giving .125. The line at the end of the fifth space of the thimble coincides with the zero line on the barrel, hence add .005 inch, making the reading $.125 + .005 = .130$ inch. Ans.

34. Since the micrometer screw is made only long enough to give dimensions from 0 to 1.000 thousandths, any whole number of inches included in the measurement must be prefixed

to the reading of the micrometer. Thus, in a 2-inch micrometer caliper, the micrometer screw will give readings only between 1 and 2 inches when the anvil and screw are arranged in such a manner that they are 1 inch apart when the micrometer is closed. In that case, 1 inch must always be prefixed to the reading. For instance, if the reading is .376 inch, the opening between screw and anvil is $1+.376=1.376$ inches.

EXAMPLE.—What is the reading of the micrometer caliper shown in FIG. 15? In this instrument the whole number of inches is shown by the number opposite the line on the bar *a* with which the line *b* on the slide coincides.

SOLUTION.—Since the line *b* on the slide coincides with line 3 on the bar, the whole number of inches is 3. There are 5 tenths-of-an-inch spaces

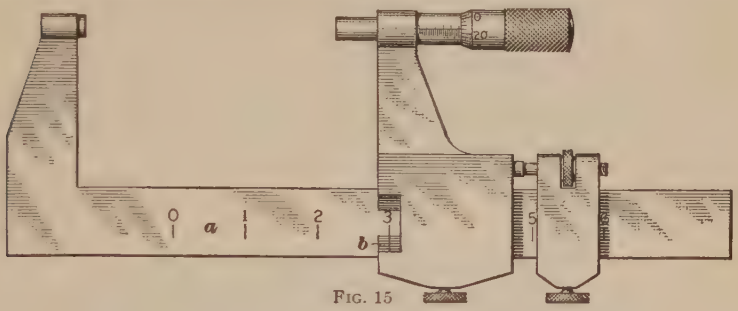

FIG. 15

exposed on the micrometer barrel, and hence 5 is the first decimal figure of the answer. There are no whole spaces between the last tenth-of-an-inch space and the end of the thimble. The line at the end of the twenty-first space of the thimble coincides with the zero line of the barrel; hence, add .021 in., making the reading $3+.5+.021=3.521$ in. Ans.

35. Setting the Micrometer.—The process of setting the micrometer is as follows: If the given dimension is .1 inch or greater, open the thimble until the figure in the tenths place is visible on the barrel. Subtract this amount from the required dimension and divide the remainder by .025 to find how many more spaces on the barrel should be shown. Subtract the amount now shown upon the barrel from the required setting and obtain the thousandths remaining by opening the thimble still farther until the line showing the proper graduation on the thimble coincides with the zero line of the barrel.

In order to set the instrument to .462 inch, open the thimble until the figure *4* appears on the barrel and 2 whole spaces beyond. This gives .45. Subtracting .45 from .462 leaves .012, which is still to be found. Then continue turning the thimble until there are 12 spaces between the zero line on the thimble and the zero line on the barrel. The instrument is now set to .462 inch.

36. Should the given dimension be less than .1 inch, proceed as illustrated in the following example: Let it be required to set the micrometer to .093 inch. There is no figure in the tenths place, hence no figure should be exposed on the barrel. Dividing .093 by .025, 3 is obtained. Hence, with the micrometer set at zero, open up the thimble 3 whole spaces. As each space gives 25 one-thousandths, the setting will then be 75 one-thousandths. Subtracting 75 one-thousandths from 93 one-thousandths leaves 18 one-thousandths as a remainder. Next turn the thimble until there are 18 spaces between the zero line on the thimble and the zero line on the barrel. The instrument is now set to .093 inch.

APPLICATIONS OF THE MICROMETER

37. Outside Micrometer Calipers.—Micrometer calipers are made in a great variety of types and sizes. Fig. 16

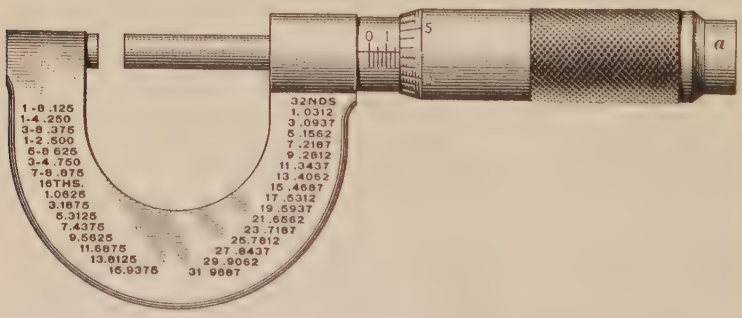

Fig. 16

illustrates a 1-inch micrometer of the *quick-adjusting* type. This instrument can be opened or closed instantly to any point within its capacity. Pressing the thumb against the plunger *a*

disengages the nut from the screw, when the screw and thimble may be moved to any desired position. When the pressure is released, the nut will immediately engage the screw. Fine adjustments are then made.

When a measurement is to be made with a micrometer caliper, the operator places the work between its measuring points, that is, between the anvil and the end of the micrometer screw. The micrometer screw is then slowly revolved until the sense of touch tells the operator that the micrometer screw is in contact with the work. The reading of the micrometer caliper is then taken.

38. Before making measurements with a new or unfamiliar micrometer caliper, the anvil and micrometer screw should be

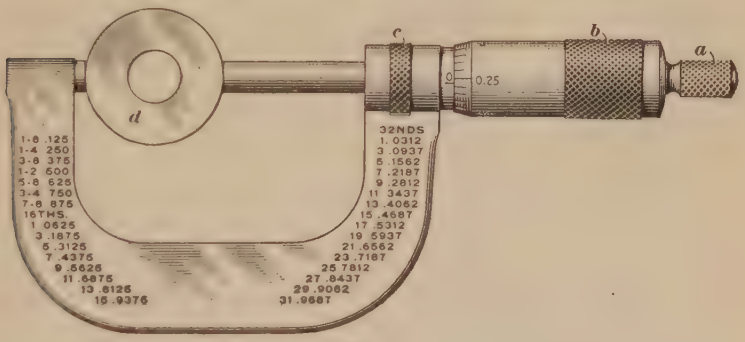

FIG. 17

brought together, and the amount of force required to bring the zero line of the thimble in line with the zero line of the barrel should be noted. The operator should then bring the micrometer screw against the work with the same force, in order to get a correct measurement.

While the micrometer caliper obtained from a reliable maker will indicate sizes correctly within an extremely small limit of variation, this fact does not imply that every one can measure within that limit. The accuracy with which a size can be measured with an accurate micrometer caliper depends almost entirely on the sense of touch of the operator and his amount of training.

39. Nearly all the modern micrometer calipers that measure in accordance with the English system of measurements are stamped on the frame with a table of the decimal equivalents of the divisions of the inch. Thus, in the micrometer calipers shown in Figs. 16, 17, and 18, on one side are stamped the decimal equivalents of eighths, sixteenths, and thirty-seconds; on the other side the decimal equivalents of sixty-fourths. This arrangement is very convenient, since, in many cases, the micrometer is used for measuring work to be finished to a

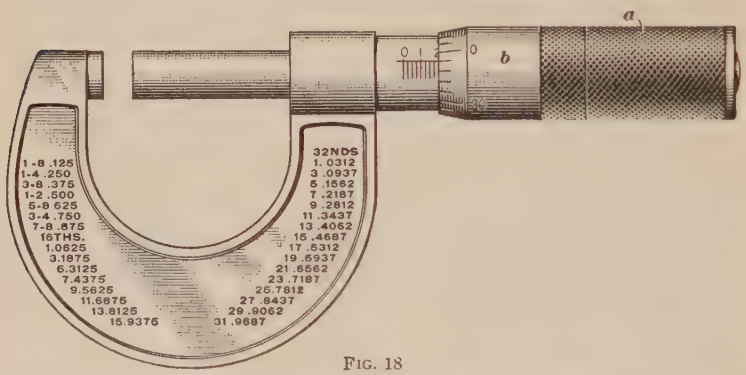

FIG. 18

dimension given in sixty-fourths. When micrometer calipers are made to measure in accordance with the metric system no decimal equivalents are needed.

For special purposes, other tables are occasionally stamped on the frame, and sometimes certain useful formulas. Thus, a special micrometer caliper intended for measuring the thickness of tubing has stamped on it the gauge numbers and the decimal equivalents of the gauge used by the tube makers.

40. A *locknut c*, Fig. 17, is frequently applied to micrometer calipers by means of which the micrometer screw may be prevented from rotating; the micrometer caliper is thus transformed into a fixed gauge adjustable for size. The circumference of the nurled extension *a*, being less than the circumference of the thimble *b*, it follows that the screw may be advanced lengthwise in less time by means of this nurled extension, which is known as a *speeder*.

41. Sometimes the speeder is attached to the thimble by a ratchet and spring in such a way that when more than a

FIG. 19

certain amount of pressure is applied the ratchet will slip, thus preventing the measuring spindle from turning further. This attachment, called the *ratchet stop*, is used for accurate measurements. Thus, inaccuracies due to the varying sense of touch of different persons are avoided.

42. An attachment known as the *friction thimble*, illustrated in Fig. 18, is applied to some micrometers. When more than a certain pressure is exerted against the measuring point of the spindle, the sleeve *a* rotates about the thimble *b* and the spindle stops advancing. This attachment serves the same purpose as the ratchet stop; its advantage is that the hand that holds the tool can also work the friction thimble.

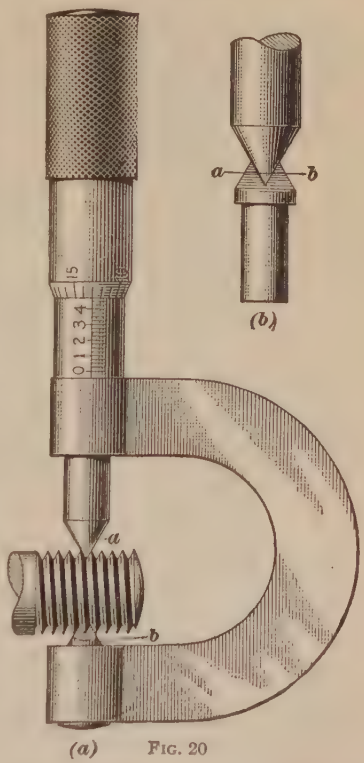

FIG. 20

43. A method of testing the setting of a 2-inch caliper is illustrated in Fig. 17. The instrument is set to the outside diameter of a standard 1-inch disk *d*. Should the reading not be 1 inch, adjustment may be made by means of a nut under the cover of the thimble *b*, which can be turned by means of a spanner wrench.

44. Micrometer Heads.—A micrometer head, Fig. 19, consists of a micrometer screw, nut, spindle, thimble, barrel, and a shank *a*. The head is applied to tools or machines when fine measurements are required, the shank *a* being held by a part of the tool or machine. For very large work, say from 12 to 48 inches in diameter, which would not warrant the expense of large metal micrometers, rigidly constructed wood frames are sometimes arranged to hold a micrometer head. Very accurate work may be done with a properly constructed instrument of this kind.

45. Micrometer Thread Caliper. — The micrometer thread caliper illustrated in Fig. 20 (*a*) is an instrument for the

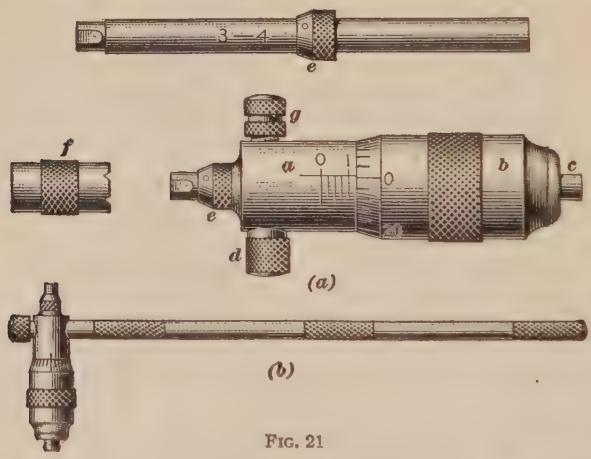

FIG. 21

accurate measurement of threads and screws. The instrument shown measures standard V threads, although this form of caliper is also made to measure United States standard and Whitworth standard threads. For threads not finer than 20 threads per inch, the same caliper may be used for both the V and United States standard threads. The cone-shaped end *a* of the screw is ground to the same angle as the angle of the thread to be measured, and the anvil *b* is V shaped. When the point and anvil are in contact, the zero represents a line *a b*, Fig. 20 (*b*). Hence, the measurement shown on the

micrometer is the distance between the top of the thread on one side [see (*a*)], and the bottom of the thread on the other side; that is, the outside diameter of the screw less the depth of one thread. Consequently, the depth of one thread must be added to the reading to obtain the outside diameter of the screw measured. These instruments are necessarily limited in capacity and different anvils are required for different ranges of threads.

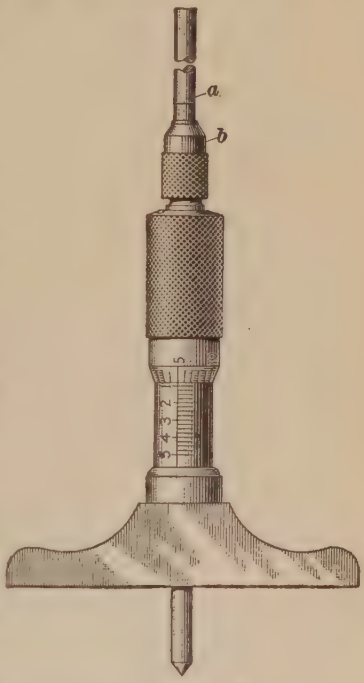

FIG. 22

46. Inside Micrometer Calipers.—An inside micrometer caliper, illustrated in Fig. 21 (*a*), is an instrument used for making close inside measurements by means of a micrometer screw. It is of considerable value in measuring for shrink or forced fits. It consists of a micrometer barrel *a* and thimble *b*, which are graduated and read just like the micrometers already described, and extension rods. The point *c* is permanently attached to the end of the thimble *b*, and the micrometer screw has a movement of $\frac{1}{2}$ inch. The extension rods, which are held in position by the clamp *d*, are provided with collars *e*, which fit snugly against the barrel *a*. An adjustment of $\frac{1}{2}$ inch is obtained by means of the standard ring *f*, which slips over the rods, thus extending the collars *e* $\frac{1}{2}$ inch from the barrel. An auxiliary handle, shown in (*b*), screws into the side of the micrometer after the screw *g*, in (*a*), has been removed, thereby adapting the tool for use in places too small for the hand. The instrument when set as shown in (*a*) will measure from 2 to $2\frac{1}{2}$ inches, in thousandths of an inch, and with the ring *f* in position from

$2\frac{1}{2}$ to 3 inches. Other measurements may be made by the use of other extension rods.

47. Micrometer Depth Gauge.—A micrometer depth gauge, Fig. 22, is an instrument used for making close measurements of depths by means of a micrometer screw. The screw in the gauge shown has a movement of $\frac{1}{2}$ inch. The rod is graduated to $\frac{1}{2}$ inches by grooves *a*. These grooves are of such depth that clamping fingers, under the cover *b*, spring into them, thus permitting $\frac{1}{2}$-inch adjustments to be quickly made. This instrument will measure depths, from zero to $2\frac{1}{2}$ inches, in thousandths of an inch.

VERNIER MICROMETERS

48. A **vernier micrometer caliper,** shown in Fig. 23, is a micrometer with a vernier scale attached for the purpose of subdividing the smallest measurement made by the micrometer itself. The true scale is represented by the graduations on the thimble, while the vernier scale is engraved on the barrel.

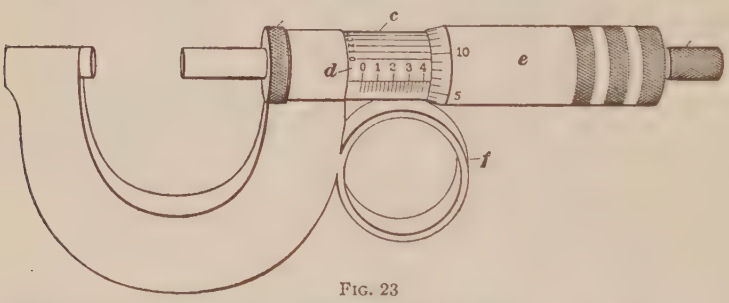

FIG. 23

Usually the micrometer reads to thousands and the vernier to ten-thousandths of an inch. Fig. 24 shows a development of the thimble and barrel; that is, the surfaces of the barrel and the thimble are shown in the illustration as if they were rolled out flat. The distance from zero to zero on the vernier scale, 10 divisions, is equal in length to 9 divisions on the true scale. The graduation lines of the vernier scale are parallel to the zero line of the barrel and extend its whole length; the zero line of the

vernier scale may be a line separate from the zero line of the barrel, or the latter may at the same time form the zero line of the vernier scale. The reading of the vernier is the same in any case.

49. Reading Vernier Micrometer Calipers.—To read a vernier micrometer, read to three decimal places as directed by the rule of Art. **33.** To obtain the fourth decimal figure, find out which line of the vernier scale coincides with a line on the thimble. Count the number of spaces from the zero line of the vernier scale to this line, counting on the vernier scale. This number is the fourth decimal figure of the reading.

EXAMPLE.—Read the vernier micrometer shown in Fig. 24.

SOLUTION.—Applying the rule of Art. **33,** the micrometer reading to three decimal places is .4+.05+.006 = .456 in. The line at the end of the third space of the vernier scale coincides with a line of the thimble. Hence, the fourth decimal figure is 3, and the complete reading of the instrument is .4563 in. Ans.

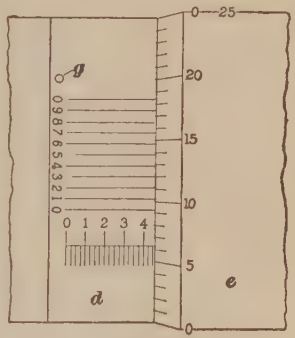

FIG. 24

50. Setting Vernier Micrometer Caliper.—In setting the vernier micrometer caliper, the thimble *e*, Fig. 23, is run back as in the regular micrometer, so as to expose the graduations on the barrel *d*, and the micrometer is set to thousandths in the ordinary manner. In order to obtain the additional ten-thousandths, or the fourth figure of the decimal, the thimble *e* is turned such a fraction of a thousandth of an inch that a line on the thimble comes opposite the desired line on the vernier scale. Thus, to set the instrument to an additional 3 ten-thousandths the line at the end of the third space on the vernier must be set to coincide with a line on the thimble.

51. Applications of the Vernier Micrometer.—The vernier scale may be applied to all the instruments described under the heading Micrometers. The instruments will then read to ten-thousandths of an inch instead of to thousandths. Fig. 23 illustrates a representative type of vernier micrometer

caliper. This micrometer is adjusted for correct zero reading of the vernier by turning the barrel *d* by means of a spanner wrench that fits in the hole *g*, Fig. 24. In addition to the vernier scale, a new feature shown on this instrument, which may also be had on the other micrometers described, is the finger ring *f*, to hold the caliper while setting and measuring.

MISCELLANEOUS MEASURING DEVICES

MEASURING MACHINES

52. A measuring machine is used to measure sizes beyond the range of the portable micrometer caliper. In most cases it is arranged to measure with a degree of accuracy not obtainable with an ordinary micrometer caliper. There are a number of measuring machines in the market that differ only in the design of the details.

53. The measuring machine shown in Fig. 25 illustrates the type that is provided with a device for noting the degree of contact with which the work is held by the measuring points. This type of machine is used for making measurements within the closest possible limits of variation. By the use of the machine illustrated, measurements may be readily made within a limit of variation of .00001 inch. This type of machine does not depend on the sense of touch of the operator for the accuracy of the measurement. It may be considered as a very refined combination of a caliper square and a micrometer, to which a special device for noting the degree of contact of the measuring points with the work has been added.

54. The machine consists of a rigid bed *a*, Fig. 25, supported on three points to obviate flexure; a stationary head *b* that carries the stationary measuring point *b'*; a sliding head *c* that carries the movable measuring point *c'* and the micrometer mechanism for moving the point and reading its movement; and finally a test bar *d*, which is graduated usually to whole inches or to 25 millimeters. The sliding head *c* is set to coincide with the graduations on the test bar *d* by means of a fine-

FIG. 25

threaded screw e; a powerful microscope f shows when the sliding head is set correctly in reference to the graduations on the bar. In the machine shown, the micrometer screw has fifty threads per inch, or a lead of $\frac{1}{50}$ inch, and it is advanced by turning the index wheel g. The index wheel g rotates, but cannot move forwards or backwards, the screw being prevented from rotating by a suitable device. As the index wheel does not move from the arm h when turned, but merely rotates, the circle carrying the graduations is always in contact with the zero on the arm h. The index wheel is divided into 400 spaces, so that each space represents a forward movement of the micrometer screw amounting to $\frac{1}{50} \times \frac{1}{400} = \frac{1}{20000}$ inch. The complete number of turns made by the index wheel is recorded on a scale, similar to that on the barrel of an ordinary micrometer, on the side of the instrument not shown in the illustration. The fractional part of a turn is shown by the graduation on the index wheel g, opposite the zero on the arm h. The fifth part of the space can readily be estimated by the eye, which would be measuring to $\frac{1}{5} \times \frac{1}{20000} = \frac{1}{100000}$ inch. The zero line from which the readings are obtained is engraved on an arm h, which can be slightly rotated about the axis of the micrometer screw by means of a suitable screw.

55. The measuring point b' of the stationary head is free to slide in its bearing; it is pushed outwards to the left by a light helical spring. An auxiliary measuring point i is rigidly fastened to the measuring point b' and moves with it. A second, but stationary, auxiliary measuring point j is fastened to the frame of the stationary head in line with i. A small, light feeling piece k is placed between the auxiliary measuring points, and determines by its behavior the degree of contact of the primary measuring points at zero and with the work. When no pressure is exerted against b', tending to push it inwards to the right, the feeling piece is subjected to the whole pressure. The friction due to the pressure exerted by the helical spring will hold the feeling piece in its horizontal position. Now let a pressure that tends to push b' inwards be exerted against b'. This has the effect of lessening the pressure on the feeling piece

until finally the friction has become small enough for the feeling piece to rotate under the influence of its own weight about the end by which it is held. Then, if the work is always measured just when the feeling piece rotates under its own weight, the degree of contact is the same, within extremely small variations, for each measurement made.

56. To adjust the machine for use, the micrometer screw in the sliding head is run all the way out and the zero line on its index wheel g placed opposite the zero line on h. The sliding head c is brought forwards and pushed against b' until the feeling piece just rotates. To get this adjustment roughly, the screw c may be used; but for final adjustment the index wheel is turned slightly. The arm h is rotated until its zero line coincides exactly with the zero of the index wheel. The microscope is next adjusted so that the line on the glass coincides with the zero line on the test bar d. This adjustment is made by moving the glass by means of the micrometer screw f', which is supplied with a graduated index wheel. The adjustment is now complete, giving the zero for the entire capacity of the machine.

57. To make a measurement the sliding head is run back and adjusted by means of the screw e until the line on the glass of the microscope coincides with a graduation on the bar corresponding to the whole number of inches of the measurement to be made. The micrometer screw is now loosened sufficiently to admit the work between c' and b'; with the work resting on the supports l, the micrometer screw is then moved until the behavior of the feeling piece indicates the correct degree of contact; the reading of the micrometer is then taken and added to that given by the test bar.

DIFFERENTIAL RULE

58. The differential rule illustrated in Fig. 26 is a rule that, by its peculiar arrangement of lines and dots, is suitable for setting dividers to thousandths of an inch. One edge of the scale, the lower one in this instance, is divided into inches and

hundredths of an inch. At the end of the hundredth graduations there are an additional nine lines, making 9 spaces *a*, the width of each space being $\frac{11}{1000}$ inch. Beyond the last line there is a row of eight dots, shown at *b*, so placed that the first dot is $\frac{12}{1000}$ inch to the right of the last of the lines *a* and each succeeding dot is $\frac{1}{1000}$ inch further to the right.

59. If the dimension is less than $\frac{1}{10}$ inch and a multiple of 11, use the lines *a*, Fig. 26, for setting the dividers. Dimensions coming under this head are easily recognized, as the first decimal digit is zero, and the second and third decimal digits are alike.

EXAMPLE.—Set the dividers to .066 inch.

SOLUTION.—Since the dimension is less than .1 in. and a multiple of 11, use the lines *a*. Put one leg of the dividers in the line at the left, and adjust the dividers until the other leg coincides with the line at the end of the sixth space. The dividers are now set to .066 in. Ans.

60. If the dimension is less than $\frac{1}{10}$ inch and the sum of multiples of 10 and 11, use the lines *a* and the hundredth spaces at the left of the lines *a* for setting the dividers, by dividing the dimension into two parts; one a multiple of .011, and the other a multiple of .010. The part of the dimension that is a multiple of .011 is laid off on the $\frac{11}{1000}$-inch spaces and the part that is a multiple of .010 is laid off on the hundredth spaces. Dimensions coming under this head may be recognized from the facts that the first decimal digit is zero, and the third decimal digit is less than the second.

61. The number of $\frac{11}{1000}$-inch spaces to be used is equal to the number in the third decimal place of the dimension to which the dividers are to be set. The part of the dimension to be laid off on the hundredth spaces is the difference between the original number and the part to be laid off on the $\frac{11}{1000}$-inch spaces.

EXAMPLE.—Set the dividers to .072 inch.

SOLUTION.—Since the first decimal digit is zero and the third decimal digit is less than the second, use the lines *a* and the hundredth spaces at the left of the lines *a*. Since the third decimal digit is 2, use two $\frac{11}{1000}$-in. spaces. The result obtained by subtracting the product of 2 and .011, or .022 in., from .072 in. is .050 in. The number of hundredth spaces to

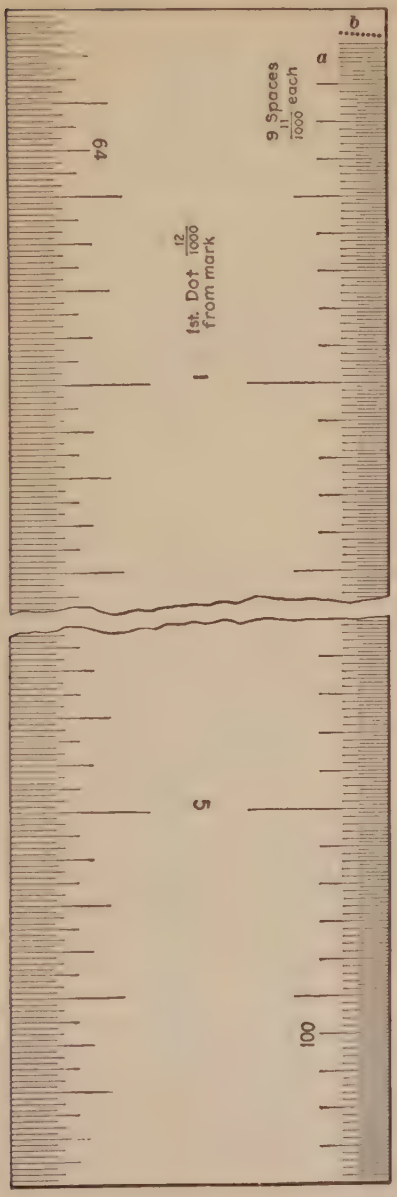

FIG. 26

be used is therefore five. One leg of the dividers is now set in the line at the end of the second $\frac{11}{1000}$-in. space, counting from the left, and the other leg adjusted to the line at the end of the fifth hundredth space, counting from the left of the lines *a*. The dividers are now set to .072 in. Ans.

62. If the dimension is less than $\frac{1}{10}$ inch and neither a multiple of 11 nor the sum of multiples of 10 and 11, use the lines *a* and the dots *b* to set the dividers. The first dot is $\frac{12}{1000}$ inch to the right of the lines *a* and should be considered as an additional $\frac{11}{1000}$-inch space plus $\frac{1}{1000}$ inch. Dimensions under this head may be recognized from the facts that the first decimal digit is zero and that the third decimal digit is greater than the second. When the given dimension is divided by .011 inch, the quotient will be the number of $\frac{11}{1000}$-inch spaces to be used and the remainder the number of dots to be used.

EXAMPLE.—Set the dividers to .079 inch.

SOLUTION.—Since the first decimal digit is zero and the

third decimal digit is greater than the second, use the lines *a* and the dots *b*. Dividing .079 by .011 the quotient is found to be 7 and the remainder 2. Hence, use seven $\frac{11}{1000}$-in. spaces and go two dots beyond. One leg of the dividers is now set in the second dot, counting from the lines *a*, and the other leg is adjusted to coincide with the seventh of the lines *a*, counting from the right. It will be remembered that the first dot is $\frac{12}{1000}$ in., or one $\frac{11}{1000}$-inch space plus $\frac{1}{1000}$ in., from the nearest of the lines *a*. The dividers will then be set to .079 in. Ans.

63. If the dimension is greater than $\frac{1}{10}$ inch, the lines *a* and the hundredth spaces to the left of them are used. The number of $\frac{11}{1000}$-inch spaces to be used is equal to the number in the third decimal place of the given dimension. The number of hundredth spaces to be used is equal to 100 times the result obtained by subtracting the product of the number in the third decimal place and .011 inch from the dimension to which the dividers are to be set.

EXAMPLE.—Set the dividers to .547 inch.

SOLUTION.—Since the dimension is greater than $\frac{1}{10}$ in., use the lines *a* and the hundredth spaces to the left of them. The third decimal digit is 7; hence, seven of the $\frac{11}{1000}$-in. spaces are used. The number of hundredth spaces to be used equals

$$100\,[.547-(7\times.011)]=47 \text{ spaces}$$

One leg of the dividers is now placed in the line at the end of the seventh $\frac{11}{1000}$-in. space, counting from the left, and the other leg is adjusted to coincide with the line at the end of the forty-seventh hundredth space. The dividers will then be set to .547 in. Ans.

MACHINISTS' INDICATORS

64. A machinist's indicator is a precision measuring instrument used to indicate inaccuracies of alinement by means of a pointer or dial.

65. Center Tester.—In Fig. 27 is shown a center tester, that is, an indicator designed to magnify the amount any point, in a piece of work held in a lathe chuck or on a face plate, runs out of true. The shank *a* of the tool is secured in the tool post of the lathe; the rod *b* is held rigidly in the universal joint *c* by the nurled nut *d*; and the rod *e* is fastened to the rod *b* at *f*.

By means of the universal joint the point g is free to swing in any direction. In operation, the point g, which is ground to a 60° angle, is brought in contact with the work to be tested. If the work does not run true, a slight variation will be magnified

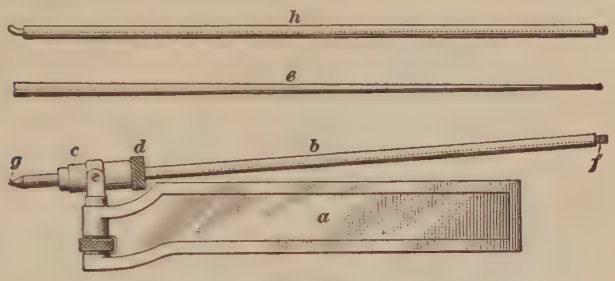

FIG. 27

many times at the end of the rod e. A rod h with a bent point may be used instead of b, thereby adapting the tool to inside and outside testing.

66. Lathe-Test Indicator.—In Fig. 28 is illustrated a lathe-test indicator that shows the amount in thousandths of an inch that the lathe center, or a piece of work held in a lathe chuck, on a lathe face plate, or between the lathe centers, runs

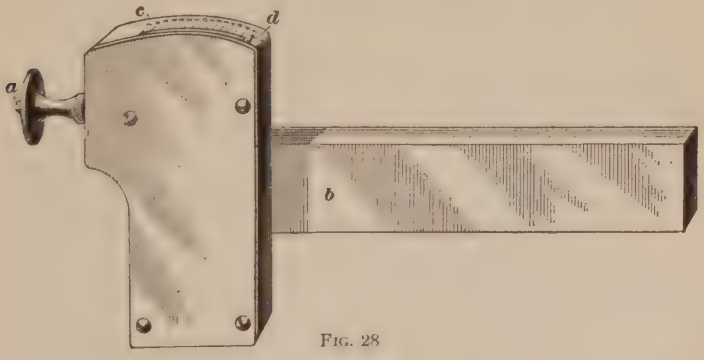

FIG. 28

out of true. In operation, the point a is made to bear against the part of the work whose truth is to be tested, the shank b being held in the tool post. The zero is in the center of the scale c and the graduations are in thousandths of an inch,

reading to 7 in both directions. The amount that the work is out of true is shown by the pointer *d*.

Fig. 29 shows how this indicator may be applied to work between the centers of a lathe. The indicator is held in the

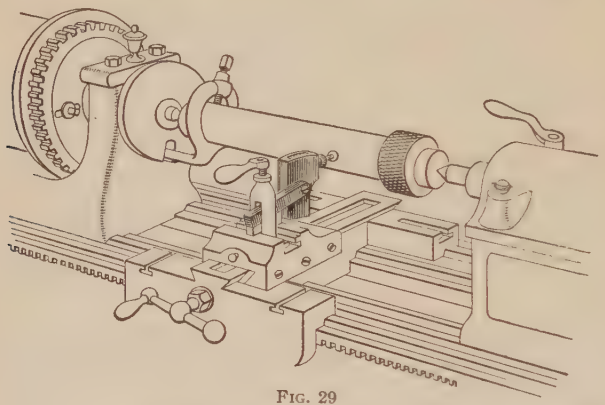

FIG. 29

tool post; the cross-slide is then fed forwards until the point touches the work. When the latter revolves, the indicating lever shows how much, if any, the work is out of true.

67. Dial-Test Indicator.—One form of indicator, known as the dial-test indicator and illustrated in Fig. 30, is used chiefly in erecting and inspecting machines. By its use the degree of inaccuracy of a plane surface on the top, bottom, or side of a piece of work may be readily determined, or the amount of end movement for example, of a spindle, or the extent to which a spindle may run out of true, easily ascertained.

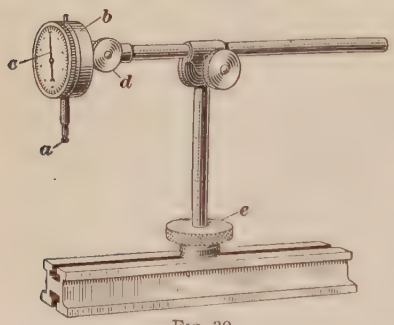

FIG. 30

The arm turns in the sleeve and may be set at any angle relative to the base, or it may be inverted so that the point *a*, which is brought in contact with the work, will point upwards. The movement of this point is magnified a number of times

and is shown on the dial *b*, which is graduated to read to thousandths of an inch. The index finger *c* may be adjusted to the zero point by means of the joint *d*, at any position of the arm. The upright post, or stand, may be clamped at any point on the base by the nurled nut *e*. The sleeve that carries the arm may be fastened at any height on the post, or may be turned around the post to bring the arm on either side.

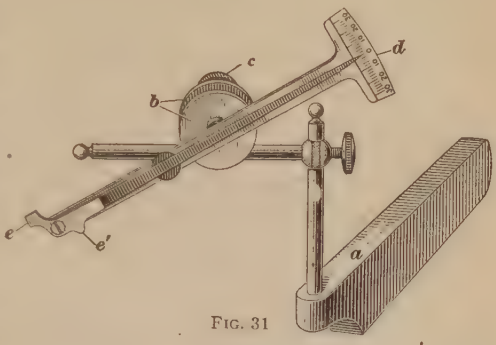

FIG. 31

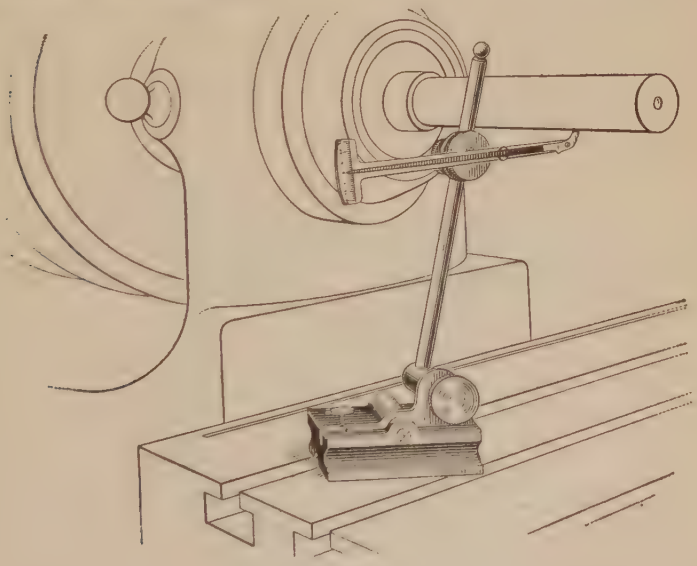

FIG. 32

68. Universal Test Indicator.—The universal test indicator, shown in Fig. 31, is designed to show imperfections of truth of inside, outside, or surface work. It may be used to

indicate the accuracy with which lathe work is turned, chucked, or centered on the face plate. When used for this purpose, the indicator is clamped to the holder *a* by means of the disk *b* and the nurled nut *c* when used for lathe work, or to the spindle of the surface gauge when used for surface work. In operation, one of the working points *e*, or *e'*, both equally distant from its fulcrum, is brought in contact with the work, causing the needle to vibrate. The amount of variation is magnified by the lever and shown on the scale *d* in thousandths of an inch. This scale is composed of thirty $\frac{2}{1000}$-inch divisions, fifteen on each side of the zero, imperfections of truth up to .03 inch being shown by the indicator. Fig. 32 shows the indicator attached to a surface gauge and used to test the truth of the arbor of a milling machine. As the arbor revolves, any imperfection in truth will be shown on the scale *b*.

DIAL CALIPERS

69. A dial caliper is a precision measuring instrument in which a pinion and rack are used to determine the measure-

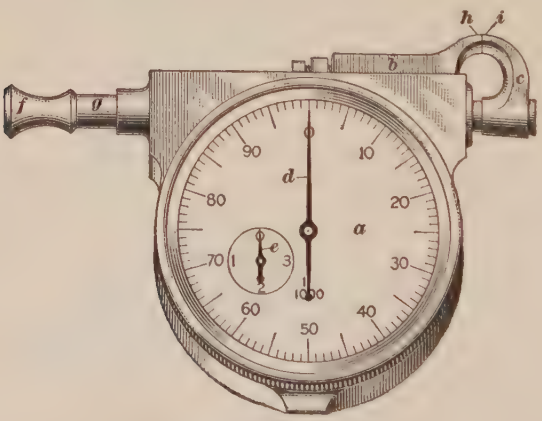

Fig. 33

ments, which are recorded on a dial, usually graduated to read to thousandths of an inch. One form of dial caliper, sometimes called a *jaw gauge* and shown in Fig. 33, is adapted for outside

measurements in thousandths of an inch up to .4 inch. It consists of a dial *a*, a fixed jaw *b*, a movable jaw *c*, a pointer *d* indicating thousandths of an inch, a pointer *e* indicating tenths of an inch, a spindle *g* to which the movable jaw *c* is attached, a finger piece *f* by means of which the jaws *b* and *c* are opened, and a spring, not shown in the illustration, which maintains a uniform pressure on the work to be measured. This work is placed between the measuring points *h* and *i* of the jaws; the pointer *e* indicates the first decimal figure of the reading and the pointer *d* the second and third figures. This caliper is much used by inspectors for testing small work as it may be adjusted and read instantly.

THICKNESS GAUGE

70. A thickness gauge, or *feeler*, illustrated in Fig. 34, is a precision measuring instrument to measure small inside dimensions, as the width of narrow gaps, slots, or spaces between surfaces. It consists of a number of leaves accurately made of

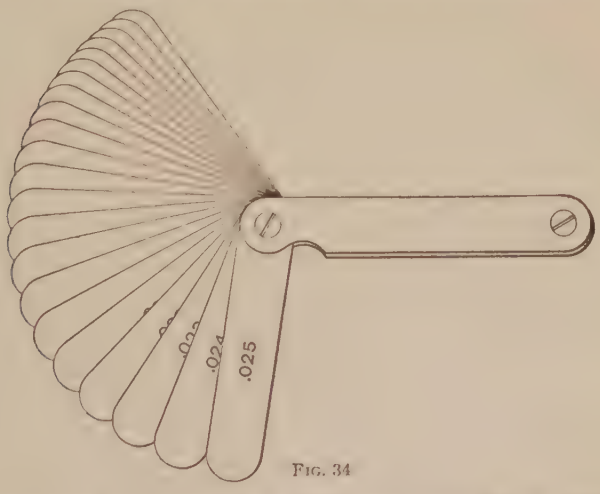

FIG. 34

hardened steel and varying in thickness from .002 to .025 inch. The thickness of each leaf is indicated by the number stamped on it. Each leaf is .001 inch thicker than the preceding one, and may be used either singly or in combination with others, thus

securing a large range of measurements. For example, by combining the leaves marked .012, .011, .010, .009, and .008, a measurement of .050 inch may be made.

CARE OF MEASURING INSTRUMENTS

71. Great care should be taken in the use of tools and instruments lest they become injured and their accuracy impaired. Instruments designed for accurate measurements are necessarily delicate in construction and hence easily disarranged. A place should be provided for every tool, and the habit of putting each tool away in its proper place after being used should be acquired. Instruments of precision are frequently kept in plush-lined cases; when no case is provided they are sometimes wrapped in chamois skin when not in use. It is of the utmost importance that the tools should not be dropped, or permitted to remain where other tools or work may be carelessly knocked against them. While the effect of dropping an accurate try square, vernier instrument, or micrometer may not be noticeable at once, yet investigation will probably show that the accuracy of the instrument has been either impaired or destroyed.

Before tools are put away, they should be examined to make sure that they are not damp, as moisture will cause steel to rust. It is well to wipe them off occasionally with an oily cloth in order to lubricate the bearings and to prevent rusting. Except in the case of instruments especially designed to work at high temperatures, they should not be allowed to come in contact with anything that is made much above the normal temperature, as the heat would tend to distort them and make them inaccurate. The practice of stamping the name of the owner on tools is not good, as it tends to spring the tools and make them unreliable. Adjustable instruments should be frequently tested to be sure the zero readings are correct, and fixed measuring instruments should be tested at intervals to make sure that the wear on the parts has not been sufficient to render them not sufficiently accurate for the purposes for which they are used.

72. Cultivating Accuracy in Use of Calipers.—The use of calipers is something that needs much practice to insure good results. The workman must accustom himself to the use of these tools and cultivate a delicacy of touch in order to use them to the best advantage. Mechanics have been known to detect a variation of $\frac{1}{2000}$ inch in the size of two cylindrical pieces with a pair of ordinary spring calipers, while others could scarcely feel any difference between two pieces that varied as much as $\frac{1}{64}$ inch. If the workman will set his calipers so that he can just feel them pass over a cylindrical piece and will then hold a piece of thin tissue paper against the side of the piece and try the caliper over both, he will soon learn to note a variation of $\frac{1}{1000}$ inch in size. Thin tissue paper varies in thickness, but may ordinarily be called $\frac{1}{1000}$ inch thick, and common newspaper, $\frac{3}{1000}$ inch thick.

Experience in calipering may be attained by centering a piece of soft steel about 1 inch in diameter and 1 foot long, and turning and grinding 10 inches carefully so that one end will be $\frac{1}{100}$ inch larger than the other; then marking ten lines 1 inch apart on the piece with a sharp-pointed tool. The diameter of the piece will now vary $\frac{1}{1000}$ inch at each line, and by trying the calipers in the various divisions one may familiarize himself with any variation that may occur between $\frac{1}{1000}$ inch and $\frac{1}{100}$ inch.

73. Opening and Closing Micrometer Calipers.—The micrometer screw should always be revolved between the thumb and finger and not by holding the thimble firmly in the hand and swinging the frame. This latter method, while an easy one, causes the hole in the frame around the smooth portion of the screw to wear out of shape, making a loose fit for the screw that impairs the accuracy of the micrometer. Whenever a micrometer is used in a dusty place, care should be taken to wipe the dust from the smooth portion of the screw.

74. Lubricating Micrometer Calipers.—As the accuracy of a micrometer or any other measuring instrument using a screw depends on the accuracy of the screw, care should be taken to keep it in the best possible condition. If thin oil is

used upon a micrometer screw, it is liable to work down upon the smooth portion of the screw where it will collect dust, and this dust will easily be carried back into the threads, thus causing undue wear, which will soon destroy the accuracy of the instrument. For lubricating the screws of measuring instruments a heavy, high-grade lubricating oil—or, better still, vaseline—should be employed. Care should be taken to use as little lubricant as will insure easy working of the parts. Any excess of the lubricant is sure to work out and collect dust.

75. Temperature Changes.—As is well known, all metals expand if their temperature is raised, hence it follows that a piece measured at a temperature above the normal will measure less when cooled. The average temperature at which measurements of length are usually supposed to be correct is about 62° F.; all gauge manufacturers adjust their gauges to be correct at that temperature. Although the temperature of the work may be normal while measuring, yet the heat from the hand will cause the instrument itself to expand. To lessen this expansion the frames of large micrometers are often wholly or partly covered with hard rubber or wood. Work should not be measured while it is warm from machining, as the contraction in cooling may be sufficient to cause a serious error.

DRILLING
(PART 1)

DRILLING OPERATIONS AND TOOLS

PARTS AND USES OF DRILLING MACHINE

CONSTRUCTION OF DRILLING MACHINE

1. The term **drilling**, as used in the machine shop, denotes the operation of sinking circular holes in solid bodies with a rotating tool called a *drill*. The drill is held and turned by a drilling machine, which, when of the upright type, is called a *drill press*, or *driller*. There are, however, a large number of other types of drilling machines, which have special names depending on their forms or on the operations for which they are to be used.

2. Essential Parts of Drilling Machine.—The modern drilling machine consists of a bed, or frame, carrying a rotating spindle at the lower end of which is a socket for the tool or the tool holder, a table on which the work is supported, and a feed-motion by which the tool is fed into the work. A type of drilling machine that is largely used for light and medium work is shown in Fig. 1, and one or more machines of this general type may be found in nearly every machine shop. There are simpler forms of drilling machines, but that shown in the illustration has all of the main parts.

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3. Driving Gear.—The spindle *a*, Fig. 1, is driven by means of a pair of bevel gears *b* and a belt running on a pair of cone pulleys *c*. The four steps on the cones furnish four different speeds, any one of which may be obtained by simply

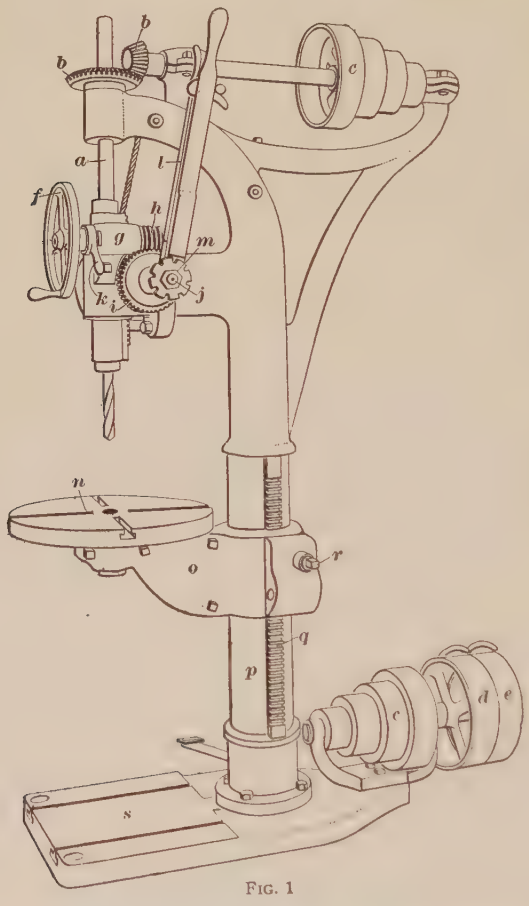


FIG. 1

throwing the belt to the desired step. A belt running from the driving pulleys *d* and *e* to a countershaft transmits the power to the drill. One of these driving pulleys is keyed rigidly to the shaft and the other runs loose on the shaft. When the belt is on the loose pulley, the drill stands still. To start the drill, the

belt is shifted from the loose pulley to the tight pulley, and thus transmits the power to the lower cone pulley *c* and to the drill.

4. Feed-Motion.—The spindle of the machine shown in Fig. 1 may be fed downwards by turning the hand wheel *f*, which is keyed to one end of a shaft that has its bearing in the box *g*. At the other end of this shaft is a worm *h* that meshes with a worm-wheel *i* fixed on the lever shaft *j*. Heavy pressure can be exerted at the end of the drill by turning the hand wheel; consequently, the feeding is done by use of the hand wheel when the machine is doing heavy work. If lighter work is to be done, the lever feed is used, in which case the hand-wheel feed must be put out of action by moving the short lever *k*. The feed-shaft *j* may then be moved by the lever *l*, which has a spring latch that can be lifted and dropped into the notches in the wheel *m* fixed to the feed-shaft. The spring latch is moved by means of a handle at the upper end of the lever *l*.

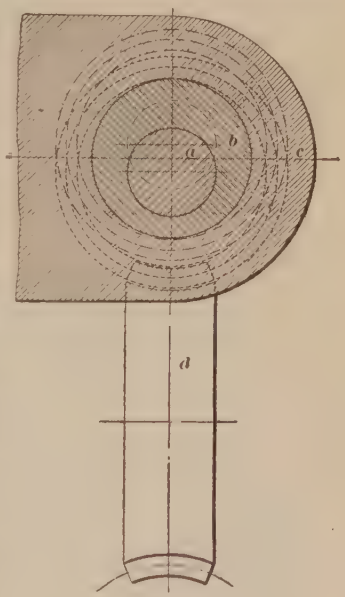


FIG. 2

5. The means by which the worm *h*, Fig. 1, is thrown out of mesh with the worm-gear *i* is simple. In the box *g* is an eccentric bushing in which the shaft of the worm and the hand wheel is carried. The eccentric bushing may be rotated by moving the lever *k*, and the worm-shaft is thus moved upwards, carrying the worm out of mesh with the worm-gear. This action may be made clearer by reference to the section in Fig. 2, in which *a* represents the shaft of the hand wheel and the worm, passing through the eccentric bushing *b* carried by the box *c*, and *d* is the worm-gear. When the eccentric bushing is in the position shown, the worm is in that indicated by the dotted circles, and

is engaged with the worm-gear; but when the bushing is turned half-way around, the shaft *a* and the worm are brought to the positions indicated by the dot-and-dash lines, and the worm is thrown out of mesh with the worm-gear.

6. Table of Drilling Machine.—The drilling-machine table *n*, Fig. 1, is supported on the arm *o* and may be rotated about its center, and both the arm and the table may be swung on the column *p*. The table may be raised or lowered by a gear that engages with the rack *q* and that is turned by a worm and a worm-gear operated by a wrench or crank applied to the square *r*. The drill foot *s* is used as an auxiliary table on which work that is too large for the table *n* may be placed.

USES OF DRILLING MACHINE

7. The drilling machine was brought into use for the purpose of sinking circular holes in solid bodies; but its use has been

FIG. 3

extended so that it is now employed also for finishing operations such as reaming, countersinking, counterboring, center drilling, tapping, spot facing, and many turning operations formerly done on the lathe and the boring mill.

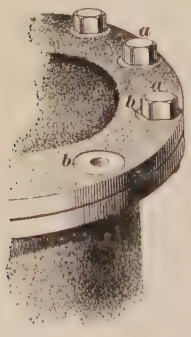


FIG. 4

8. The varying hardness of the metal, blowholes in castings, and slight imperfections in the form of the tool tend to make a drilled hole imperfect. Sometimes the hole is not quite straight, or it may not be quite round, or the surface may be rough, so that an additional operation may be needed to bring it to correct shape and size. The operation of running a reamer through a drilled hole to straighten the hole, smooth it, or bring it to size, is called **reaming.**

9. Countersinking is the operation of enlarging the end of a hole conically as shown in Fig. 3 (*a*), so as to take the tapered head of a screw or a machine part.

10. Counterboring is the operation of enlarging the end of a hole, as shown in Fig. 3 (*b*), so that the sides of the enlarged part are carried straight down and a flat shoulder is formed at the bottom.

11. Spot facing is the operation of finishing a piece of work for only a short distance around the end of a drilled hole, to form a smooth bearing surface for the head or the nut of a bolt, or for the hub of an adjoining part. An example of spot facing is shown in Fig. 4, in which, to form flat bearing surfaces for the heads *a* of the bolts, the spots *b* are faced on the cylinder head.

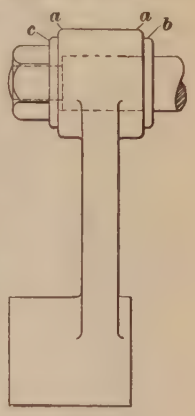


FIG. 5

12. Facing is the operation of finishing the ends of a hub, or of a similar part, by a flat revolving cutter held in a bar. For example, the rocker-arm in Fig. 5 has its end surfaces *a* faced to form bearing surfaces for the collar *b* and the washer *c*.

13. Center drilling is the operation of forming a center hole in a piece of work for a lathe, by the use of a drill and a center reamer.

14. Tapping is the operation of cutting an internal screw thread in a piece of metal by the use of a tap. One form of tap,

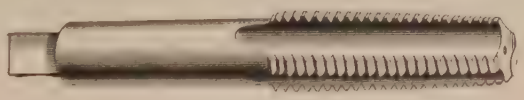


FIG. 6

or tool used for this operation, is shown in Fig. 6. It consists of a tapering screw of hardened steel that is grooved, or fluted, to give a series of cutting teeth that form the thread when the tap is turned in the hole.

DRILLING TOOLS

CLASSIFICATION AND MAIN FEATURES

15. The drill is one of the most extensively used tools found in the machine shop and is made in a number of different forms. These various forms may be divided into two main classes, namely, *flat drills* and *twist drills*.

FIG. 7

16. Main Features of Drills.—Every drill, no matter of what kind, must have three main features. First, there must be one or more cutting edges that remove the material either by scraping or by cutting. Second, there must be a central leading point about which the cutting edges revolve and which guides the drill through the material. This is obtained by tapering the cutting edges toward the center, as shown in Fig. 7. The angle *a* of this taper varies for different classes of work, but for ordinary drilling it is made between 50° and 60°. The Morse Twist Drill Company recommends 59°, while Wm. Sellers & Co. recommend 52°. Third, there must be a clearance back of the cutting edge. Fig. 8 represents the point of a flat drill, in which *b* is the *clearance angle*, sometimes called the *angle of relief*. This angle should be large enough so that the stock back of the cutting edge will not bear against the work.

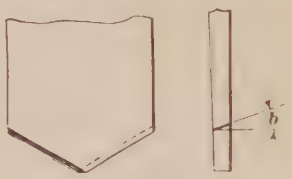


FIG. 8

FLAT DRILLS

17. Form of Drill Point.—The simplest and most cheaply made machine-shop drill is the ordinary flat drill shown in Fig. 9. When rightly formed, this type of drill does very good work. It is, however, a hand-made tool and is often

so poorly formed and so imperfectly ground that its work is not satisfactory. If a drill is to cut equally on both sides and form a smooth, round hole, having the same diameter as the drill, five conditions are necessary: the point must be in the center, the cutting edges must make equal angles with the center line, and must be of the same length and have equal clearance angles, and the sides should be parallel.

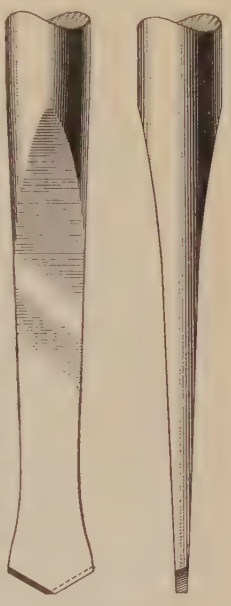


FIG. 9

18. Results of Improperly Formed Drills.—It is not sufficient to have the point in the center of the drill, because different angles of the cutting edges will cause the drill to cut on one side only, as shown in Fig. 10 (*a*), thus throwing twice the intended depth of cut on the one cutting edge. It also causes a crowding against one side, and a tendency to throw the center of the drill out of its correct position. The angles that the cutting edges make with the center line may be equal, but if the lengths of the cutting edges are not equal, the hole will be larger than the drill, as shown in (*b*). The outer end of the long side of the cutting edge will then do double duty, which will soon dull it, cause crowding, and make a rough hole.

19. When both the angles with the center line and the lengths of the cutting edges are unequal, the hole will be larger than the drill, and the effect will be as shown in Fig. 10 (*c*); that is, all the work will be done by the short side and the outer end of the long side. Unequal clearance angles will cause one side to cut more freely than the other, thus distributing the work unequally. Under a given pressure, the side with the greater clearance angle tends to take a deeper cut than the other, while there is less metal to support its cutting edge. This edge wears away more rapidly than the other, resulting in unsatisfactory working conditions.

20. Advantages of Thin Drill Point.—In the flat-drill point shown in Fig. 11, the cutting edges *a b* and *c d* are of equal lengths, the clearance angles are equal, and the edge *b d* at the point of the drill is at right angles to the center line of the drill.

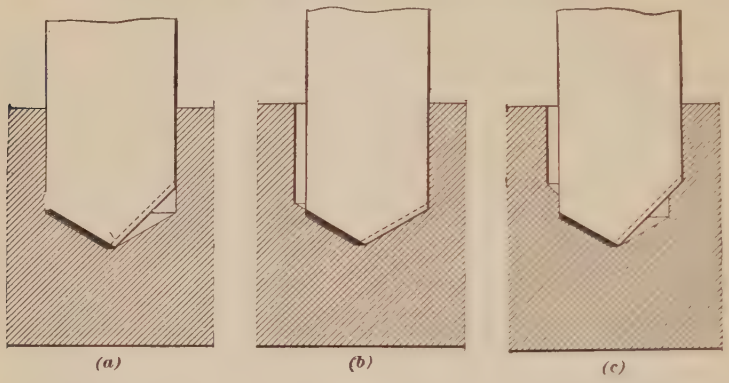


FIG. 10

When the drill turns, the edge *b d* acts as a scraping edge instead of a cutting edge, and the pressure required to force it through the metal at the rate at which the drill should cut is very great compared with the pressure required on the cutting edges. The scraping edge wears rapidly, and as it grows dull the pressure required to feed the drill becomes greater. To reduce this pressure, the scraping edge should be shortened. Shortening is done by making the drill thin at the point; however, it must not be too thin, or the cutting edges will not be supported sufficiently and will break, and the drill will need to be reground frequently.

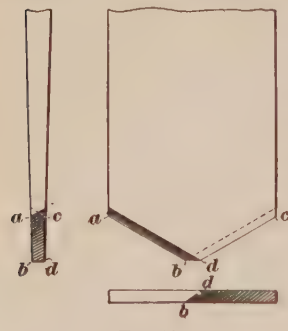


FIG. 11

21. Grooved Drill Point. Sometimes grooves are formed in the end of the drill, as shown in Fig. 12, thus providing curved cutting edges, that, when properly shaped, remove most of the scraping edge. This practice, however, tends to weaken the inner ends of the cutting

edges by removing the supporting metal, and it is generally thought to be better simply to make the end of the drill as thin as practicable.

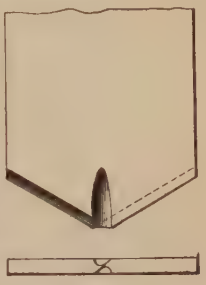


FIG. 12

22. Parallel Sides for Drills.—Flat drills, to give the best results, should have the sides *a b*, Fig. 13 (*a*), parallel for a distance of $\frac{1}{2}$ inch or more above the cutting edges. This parallel part should be rounded to fit the circumference of the hole. Drills are often used with the corners projecting beyond the body, as shown in (*b*), and with the sides beveled, as shown in (*c*). Drills formed in this way make ragged holes, and when there are soft or hard spots or blowholes in the material drilled, they run off to one side, making holes that are not straight, round, nor smooth. The simple precaution of making the sides parallel for a short distance and rounding the edges to fit the hole, as shown in (*d*), will, when the point is rightly formed, obviate this difficulty almost entirely.

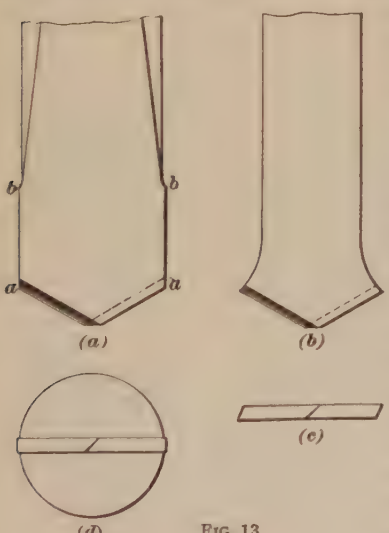


FIG. 13

23. Drill Shank.—The part of the drill between the cutting part and the upper end is called the *shank*. It should be somewhat smaller than the hole, in order to work freely in it. In the case of comparatively shallow holes, the flat part should extend to a point high enough so that the cuttings or chips can work out. The shank should be round, as the corners of any angular section draw the chips under them and clog the drill. Even with a round shank and a perfectly formed drill, there will be more or less clogging in a deep

hole, and it is often necessary to back out the drill and remove the cuttings.

24. Lipped Drill.—The ordinary flat drill has the front face, or the face above the cutting edge, either at right angles to the direction of motion, as in Fig. 14 (*a*), or else slanted forwards a little, as in (*b*). If the face is slanted backwards just above the cutting edge, the drill will cut more easily. The tool is then said to have *front rake*. One way of doing this is to grind a groove just above the cutting edge, as shown in Fig. 15 (*a*). A section along the line *c d* is shown in (*b*). Another way is to form the tool with a lip at the cutting edge, as in (*c*). A section of this drill on the line *e f* is shown in (*d*). In each of the drills shown in (*a*) and (*c*), care must be taken to leave enough metal back of the cutting edge to withstand the cutting strain.

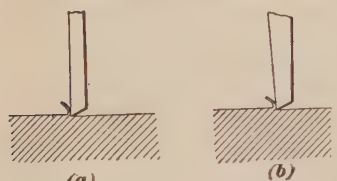


FIG. 14

25. Twisted Flat Drills.—One disadvantage of lipped drills is that grinding reduces the lip, and necessitates frequent reforging, or dressing. This objection may be overcome by twisting the end of the drill into a spiral, as shown in Fig. 15 (*e*). In this way, the same angles of the cutting edges may be obtained, but the shape is not altered by grinding, until the entire spiral is ground away. The spiral also assists in carrying the cuttings away from the drill point.

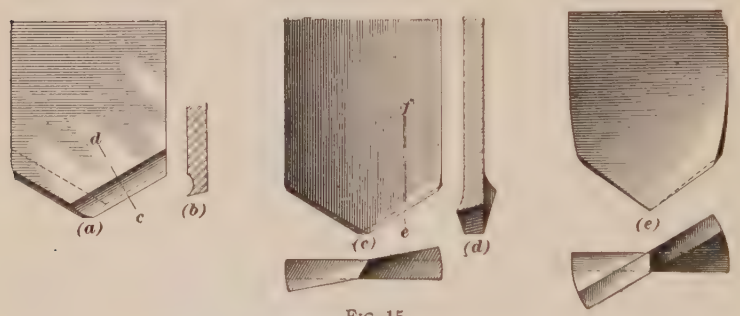


FIG. 15

TWIST DRILLS

26. Ordinary Twist Drill.—The twist drill is in universal use because it removes its cuttings, requires no reforging, and can be resharpened repeatedly by a simple grinding operation. Fig. 16 (*a*) illustrates an ordinary commercial drill of this type. It is generally made from round stock, the spiral flutes being cut with a milling cutter, or else formed by rolling or forging. The surface between the flutes is backed off slightly from near the cutting edges *a*, Fig. 17 (*a*), to the backs *b* of the flutes, leaving only narrow strips *a c* the full diameter of the drill. This is done to reduce the bearing surface on the side of the hole, but enough surface is left to form a perfect guide, owing to the fact that the bearing *a c* runs in a spiral around the drill. In some drills a narrow bearing strip is left, as shown in Fig. 16 (*b*), the clearance being cut away, concentric with the bearing surface, as illustrated in Fig. 17 (*b*).

FIG. 16

Twist drills are also made with three or four grooves or lips, and are sometimes called *reamers*. They are similar to the ordinary twist drill in most of their details. The cutting end, however, is left square and is beveled for one-quarter or one-third of the diameter of the drill to form cutting edges. These drills will not cut from the solid, but are used for reaming cored holes or for reaming holes made by a flat or twist drill. They are used for jigwork in the drilling machine, and largely for turret-lathe work.

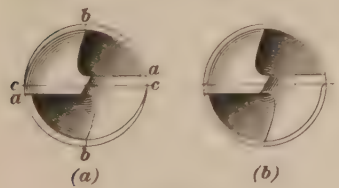


FIG. 17

27. Twisted Drill.—The twisted drill, shown in Fig. 18, is a form that resembles the twist drill. It is made from flat stock or from stock that is

rolled thinner at the middle than at the edges, and that is then twisted to the required form and ground. The shank is usually flat, but it may be made round, like that of a twist drill. The advantages claimed for the twisted drill are that it requires little stock in manufacture, has a large space for chips, and may be hardened and tempered more easily than the twist drill. It is made from rolled stock, and the compressing of the material during the rolling process increases its strength, so that the drill is less likely to split up the center.

Fig. 18

STRAIGHT-FLUTED, SLOT, AND TEAT DRILLS

28. Straight-Fluted Drill.—The straight-fluted drill, shown in Fig. 19, is best suited for drilling thin plates and brass. There is a tendency for a twist drill to plunge forwards as it comes through the piece being drilled. By making the flutes of the drill straight instead of spiral, this tendency is overcome.

Fig. 19

29. Forms of Slot Drills.—In drilling machines in which slides that feed perpendicular to the center line of the spindle are provided, slot, or keyway, drills are often used. These are made in a number of different forms. In Fig. 20 (*a*), (*b*), (*c*), and (*d*) are shown four different kinds, all of which are quite satisfactory in metal of uniform hardness. In sinking these drills into the metal, holes are formed as shown in (*e*), (*f*), (*g*), and (*h*). The central cores in (*e*) and (*f*) form guides for the drill, which, in metal of varying hardness, have been found of great advantage.

30. Use of Slot Drills.—Slot drills are used largely in forming keyways, or slots, in shafts. They are sunk into the metal to a sufficient depth for a longitudinal cut and are then fed lengthwise along the shaft, thus cutting out the metal to this depth throughout the entire length of the slot. The drill is then lowered enough to furnish another longitudinal cut and the operation is

repeated until the required depth is obtained. The drills shown in Fig. 20 (*c*) and (*d*) may be used in squaring the bottoms of holes made by an ordinary twist drill at the ends of keyways to be planed or chipped.

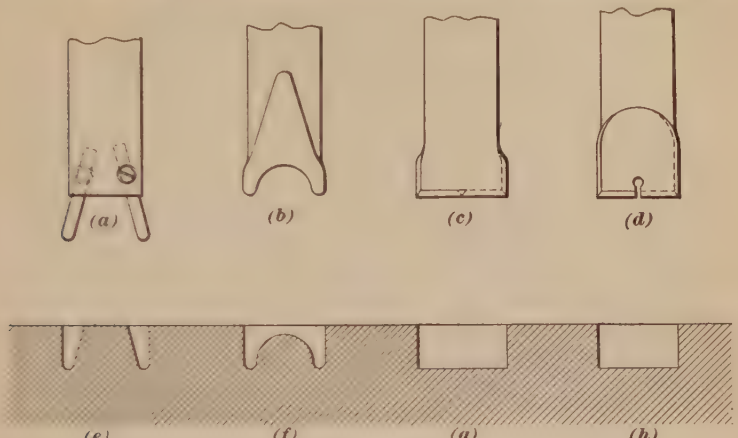


FIG. 20

31. Teat Drill.—The teat drill is made like an ordinary flat drill, except that its cutting edges are at right angles to the center line of the drill, as shown in Fig. 21. Instead of the scraping edge found in the flat drill, however, there is a teat *a* that has cutting edges on opposite sides and that serves to guide the drill. The teat drill is largely used for flattening the bottoms of holes made with ordinary drills, but sometimes it is used to drill a hole to the entire depth. It is very suitable for drilling holes in sheet metal, particularly in brass and copper. The teat is a four-sided pyramid, and the corners nearest the cutting edges of the drill are in the lead, thus providing good cutting edges for the point, and giving it proper clearance.

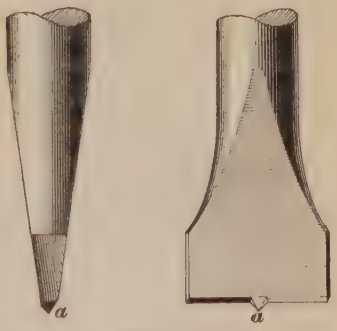


FIG. 21

ANNULAR CUTTERS

32. Single-Tool and Double-Tool Cutters.—A form of annular cutter that is used very generally for removing large bodies of metal and cutting large holes in boiler plates, rod ends, etc., is shown in Fig. 22. The tool *a* is a right-angled cutting-off tool, with the proper side clearance to clear the circular sides of the hole. A hole *c* is first drilled for the guide pin *b*, after which the stock around the hole *c* is removed as a washer with a hole in the center. Sometimes two tools are used, one on each side of the center, as shown in Fig. 23. This balances the side thrust on the center pin *b* and reduces it to a minimum, besides doubling the capacity of the tool.

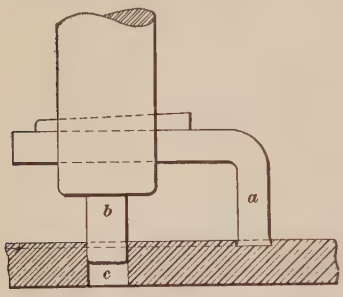


FIG. 22

33. Hollow and Butt Mills.—The hollow mill, shown in Fig. 24, is a tool that is occasionally used in a drilling machine to form a turned or finished projection on a machine part. The center is hollowed out to the diameter of the required boss or projection, and the depth of this hollow center is great enough to give the proper length of the projection. Four cutting edges are formed at the bottom of the tool.

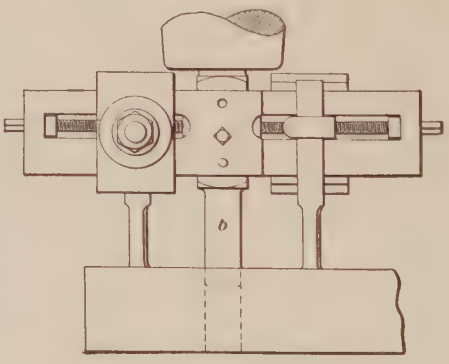


FIG. 23

The butt mill differs from the hollow mill in that it is made solid instead of hollow, has more teeth, and has the latter cut to only about half the depth of the teeth on the hollow mill. It is used to flatten the conical

bottoms of holes and to remove the metal between adjoining holes drilled in a row. When used for the latter purpose, it

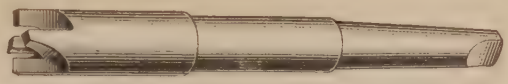


FIG. 24

is usually held and driven by a drill chuck and guided by a drilling jig.

34. Hubbing Tool.—A very useful form of tool, known as a hubbing tool, is shown in Fig. 25. A hub *a* of the piece *b* is to be finished as shown at *c*. The tool with which this is done consists of a center bar *d*, which fits the bore of the hub, and a tool *e* supported on the arm *f*. As the tool is rotated about the center of the pin, it cuts a perfect circle.

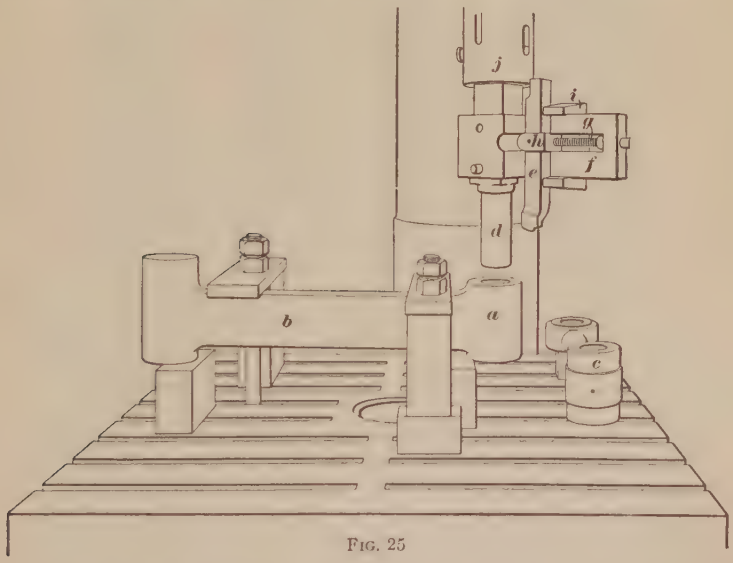


FIG. 25

The device is attached to the spindle *j* of a heavy drilling machine, the work being fastened on the table. The radius at which the tool cuts is regulated by the adjusting screw *g* and a clamp *h* and *i*.

DRILL SHANKS

35. Straight Shank.—On ordinary flat drills, the forms of shanks shown in Fig. 26 (*a*) and (*b*) are quite commonly used. In (*a*) the shank is straight and slightly flattened at *a* to furnish a good bearing for the setscrew. The end of the screw often cuts a burr at the bearing point, which prevents the easy removal of the drill, and to avoid this the shank may be turned down slightly at the bearing point of the screw, as shown at *a* in

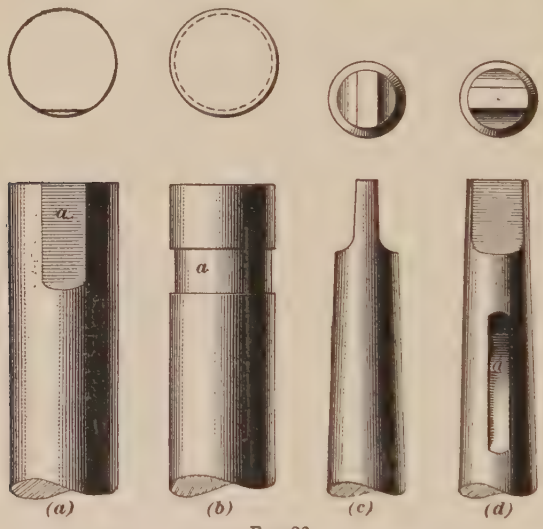


FIG. 26

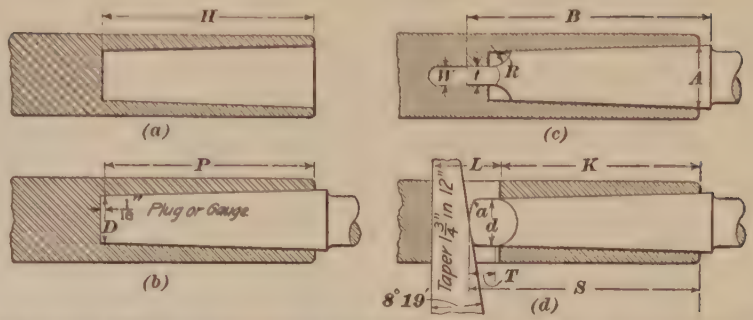
view (*b*). The shoulder also prevents the tool from dropping out of the socket when the screw becomes slightly loose.

36. Taper Shank.—The taper shank, shown in Fig. 26 (*c*) and (*d*), is used because it centers the drill, gives considerable friction in the socket to help to drive the drill, and is easily removed from the socket. The taper is made slight enough to cause the socket to grip the shank and prevent the drill from dropping out of its own weight. The flattened end, called the *tang*, helps to turn the drill, as it fits a corresponding hole in the socket. Several different tapers are used by different makers of drills, the most common being the Morse taper, which is about

TABLE I

MORSE TAPERS

(From Morse Twist Drill and Machine Company)



Number of Taper	Diameter of Plug at Small End	Diameter at End of Socket	Standard Plug Depth	Whole Length of Shank	Depth of Hole	End of Socket to Keyway	Length of Keyway	Width of Keyway	Length of Tongue	Diameter of Tongue	Thickness of Tongue	Radius of Mill for Tongue	Radius of Tongue	Shank Depth	Taper per Foot	Taper per Inch	Number of Key
	D	*A*	*P*	*B*	*H*	*K*	*L*	*W*	*T*	*d*	*t*	*R*	*a*	*S*			
0	.252	.356	2	$2\frac{11}{32}$	$2\frac{1}{32}$	$1\frac{15}{16}$	$\frac{9}{16}$	.160	$\frac{1}{4}$	.235	$\frac{5}{32}$	$\frac{5}{32}$	.04	$2\frac{7}{32}$	.625	.05208	0
1	.369	.475	$2\frac{1}{8}$	$2\frac{9}{16}$	$2\frac{3}{16}$	$2\frac{1}{16}$	$\frac{3}{4}$	.213	$\frac{3}{8}$	.343	$\frac{13}{64}$	$\frac{3}{16}$	.05	$2\frac{7}{16}$	.600	.05000	1
2	.572	.700	$2\frac{9}{16}$	$3\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{1}{2}$	$\frac{7}{8}$	.260	$\frac{7}{16}$	$\frac{17}{32}$	$\frac{1}{4}$	$\frac{1}{4}$	.06	$2\frac{15}{16}$	.602	.05016	2
3	.778	.938	$3\frac{3}{16}$	$3\frac{7}{8}$	$3\frac{1}{4}$	$3\frac{1}{16}$	$1\frac{1}{16}$	.322	$\frac{9}{16}$	$\frac{23}{32}$	$\frac{5}{16}$	$\frac{9}{32}$	.08	$3\frac{11}{16}$	.602	.05016	3
4	1.020	1.231	$4\frac{3}{16}$	$4\frac{7}{8}$	$4\frac{1}{8}$	$3\frac{7}{8}$	$1\frac{1}{4}$	.478	$\frac{5}{8}$	$\frac{31}{32}$	$\frac{15}{32}$	$\frac{5}{16}$	.10	$4\frac{5}{8}$	.623	.05191	4
5	1.475	1.748	$5\frac{3}{16}$	$6\frac{1}{8}$	$5\frac{1}{4}$	$4\frac{15}{16}$	$1\frac{1}{2}$	.635	$\frac{3}{4}$	$1\frac{13}{32}$	$\frac{5}{8}$	$\frac{3}{8}$	.12	$5\frac{7}{8}$	.630	.05250	5
6	2.116	2.494	$7\frac{1}{4}$	$8\frac{9}{16}$	$7\frac{3}{8}$	7	$1\frac{3}{4}$	.760	$1\frac{1}{8}$	2	$\frac{3}{4}$	$\frac{1}{2}$	.15	$8\frac{1}{4}$	.626	.05216	6
7	2.750	3.270	10	$11\frac{5}{8}$	$10\frac{1}{8}$	$9\frac{1}{2}$	$2\frac{5}{8}$	1.135	$1\frac{3}{8}$	$2\frac{5}{8}$	$1\frac{1}{8}$	$\frac{3}{4}$	.18	$11\frac{1}{4}$	.625	.05208	7

$\frac{5}{8}$ inch per foot. Table I shows the dimensions of Morse taper shanks and sockets. Sometimes a key is inserted in the socket to prevent the drill from turning, and a keyway must then be cut in the drill, as shown at *a*, view (*d*).

37. Short Shanks and Sockets.—The standard sizes of drill shanks and tangs were adopted years ago and were considered strong enough for the requirements of that time; but the tangs have often broken off, as shown at *a*, Fig. 27 (*a*), when the drills were used in modern drilling machines, due to the greater strain resulting from the higher speeds and the harder or tougher materials. A drill with a broken tang may be held and driven by a setscrew that passes through the socket and bears

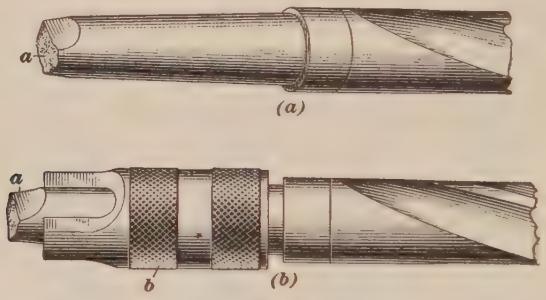


Fig. 27

on a flat formed on the taper shank. Another method is to turn down the broken end and to cut a new tang of standard size on it; or, the taper shank may be left just as it is, and a new tang may be cut on it. In the latter case, however, the shank will be short and will require a shorter drill socket. Gauges for short tangs are made for the different sizes of taper shanks. One of these is shown at *b* in view (*b*), in position on the shank of a broken drill. The form of the new tang is marked off by scribing along the gauge, and the metal is then cut away. The new tang thus made is considerably stronger than the old one. Drills are sometimes made with two tangs on the shank, the larger one corresponding to the short form just described and the smaller one being of standard size. If the smaller tang breaks, the drill is then used in a short socket.

38. Special Forms of Drill Shanks.—The taper shanks of twist drills are commonly made smaller in diameter than the drills, but special drills are made as shown in Fig. 28 (*a*), with taper shanks one or two sizes larger, to prevent breakage. Drills having square tapered shanks, as shown in (*b*), are used in ratchets; also, the square shank is often formed on flat drills forged in the smith shop, as it is cheap and easily made of any

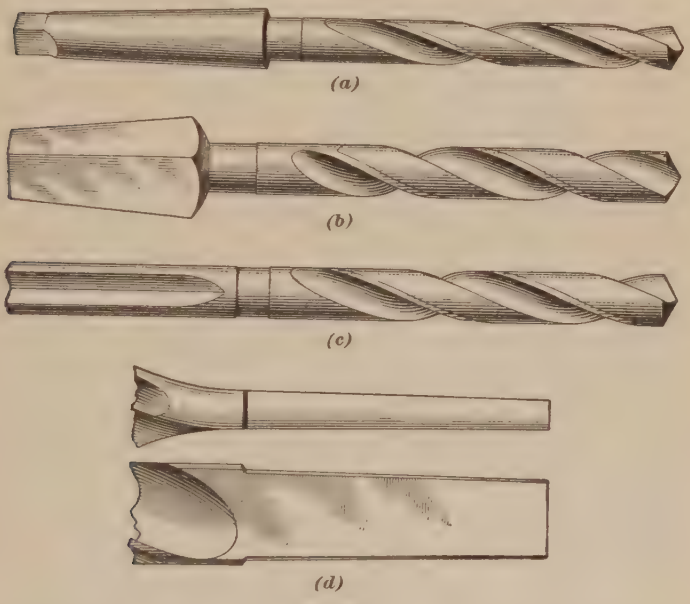


FIG. 28

required size. Drills with straight shanks are apt to slip in the chuck, thus wearing both the chuck jaws and the drill shanks. To prevent this, two V-shaped grooves are cut in the opposite sides of the shank, as shown in (*c*), and use is made of a special chuck having two jaws that enter the grooves. The flat shank shown in (*d*) is also intended to prevent slipping. It is of standard taper and is used in a special socket. Special forms of drill shanks and methods of driving are required largely where high-speed drills are used, as more power is required to drive such drills at the speed at which they do the best work.

LUBRICATION OF DRILLS

39. Application of Lubricants.—In drilling wrought iron and steel, the drill point must be lubricated. The lubricant is usually applied by dropping it into the hole and permitting it to run down along the sides of the hole and the drill. This method has been found rather unsatisfactory, as the cuttings, in working their way to the surface, tend to carry the lubricant up, and in some cases very little, if any, reaches the drill point where it is most needed.

FIG. 29

40. In Fig. 29 (*a*) is shown a very simple method by means of which better lubricating conditions are obtained. Two spiral grooves *a* are cut parallel with the flutes *b*, thus forming separate channels for the lubricant. There is some danger that these grooves may become clogged by fine particles that work around the drill, and small brass tubes are brazed into the grooves, as shown, in order to insure an unobstructed flow to the drill point. Another way is to make the drill with holes running through the solid metal, as shown in (*b*). These drills are made from straight-fluted stock in which the oil holes are drilled before the drills are heated and twisted.

41. Provision for Supplying Lubricants.—The lubricants may be carried to the holes in the drill through the socket or through a small attachment at the lower end of the socket. Fig. 30 illustrates an attachment that is frequently used. A collar *a* is fitted to the lower end of the drill socket, as shown, and is kept from turning with the spindle by a pipe that rests against the column of the machine and through which the oil is conveyed to the collar. Inside the collar, and immediately over a pair of holes in the socket that correspond to the upper holes in the drill, a circular groove *b* is turned, thus forming a connection between the

outer pipe *c* and the drill. The oil is supplied by an oil pump, under sufficient pressure to insure a steady flow to

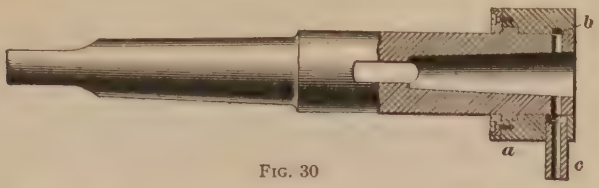


FIG. 30

the drill point, and is carried to the attachment by a flexible tube.

REAMERS

42. Machine Reamers.—The usual type of machine reamer consists of a piece of round steel having a shank formed at one end and a series of lengthwise flutes cut at the other end. If the fluted part is of the same size throughout, the reamer is a straight reamer. Two forms of straight reamers are shown in Fig. 31. That shown in (*a*) is known as a *chucking reamer*. A very slight bevel is formed on the points of the teeth, as shown at *a*, and the cutting edges thus produced remove the stock to a depth of $\frac{1}{64}$ inch or less. The remainder of the fluted part, which is of uniform size, smooths the hole. The *rose chucking*

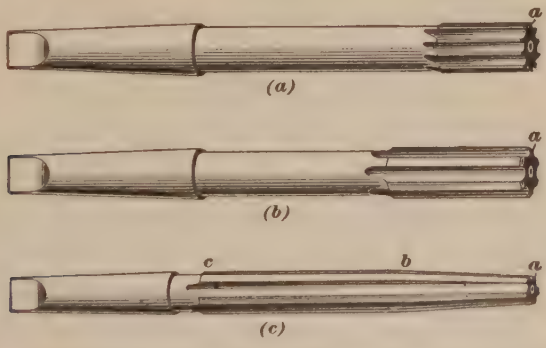


FIG. 31

reamer, shown in (*b*), has only about half as many flutes as the ordinary chucking reamer and is beveled considerably more at

the ends of the teeth, as shown at *a*. The teeth are heavier, and remove considerably more metal than those of the chucking reamer. A reamer for bridge and boiler work is shown in (*c*). The tapered part from *a* to *b* removes the metal and the straight

FIG. 32

part from *b* to *c* smooths the hole. Machine reamers are often made .003 inch under size, to allow for hand reaming; and if they are made to size, they wear under size by use.

43. Hand Reamers.—A type of hand reamer is shown in Fig. 32. The fluted part is about twice the length of the fluted part of a machine reamer of the same size. Near the middle, the hand reamer is necked down, as shown at *a*, and the shank *b* is ground accurately to the size of the reamer. The upper end *c* is squared to take a wrench, by which the reamer is turned. For a short distance from the bottom end, the fluted part is tapered about .005 inch so as to enter the hole easily. Some makes of hand reamers have a shallow screw thread cut for a short distance from the lower end, so that they will feed more easily. Hand reamers are used for finishing holes reamed by machine reamers. They remove from .003 to .005 inch of metal, and leave a smooth, true hole.

44. Shell Reamers.—An ordinary shell reamer of the form commonly used in the shop is shown in Fig. 33. A hole *a* having a taper of about $\frac{1}{16}$ inch to the foot extends through it, and across the top are cut two grooves, one of which is shown at *b*. The grooves fit over lugs on the shank by which the reamer is held, and thus enable the shank to drive the reamer without any slip. Shell reamers are cheaper than solid reamers and occupy less storage space in the tool room; also, when they wear out, only the shell needs to be replaced, as the shank is a separate piece.

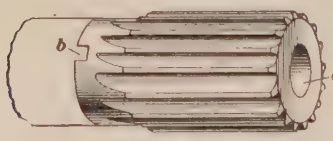
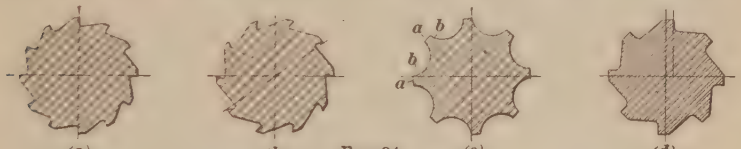


FIG. 33

45. Cutting Faces of Reamers.—The sections of several kinds of reamers shown in Fig. 34 serve to illustrate the forms of the cutting faces. Ordinarily, the front faces of the teeth lie on the center line through the section, as in (*a*). They should never be undercut, as in (*b*), or the reamer will chatter; chattering will cause the teeth to gouge into the metal, and the result will be a damaged or enlarged hole, or possibly a broken reamer. If the reamer is made as shown in (*c*), with curved faces *a* and *b*, there will be no chattering, as the edges will take a scraping cut. The form shown in (*d*) is a special form used for brass. The cutting faces are set forward from the center line but parallel to it, the distance between the two being increased as the size of the reamer increases.

46. Number of Cutting Edges.—A reamer should always have enough cutting edges to guide itself in a straight



(*a*) (*b*) FIG. 34 (*c*) (*d*)

line through the hole. There should never be less than four, and where the diameter is large enough to make it practicable there should be more. The number of edges should be even and not odd to make it possible to caliper the reamer, unless a ring gauge is used, in which case the number of edges does not matter.

47. Allowance for Reaming.—In all classes of reaming, the holes should be drilled as nearly to the finished size as possible, so that the reamer need take only a light finishing cut. This preserves the edges, avoids frequent grinding, and lengthens the life of the reamer. An allowance of $\frac{1}{64}$ inch of stock is usually sufficient for reaming in holes having a diameter of 1 inch or less, while in holes having diameters between 1 and 2 inches, $\frac{1}{32}$ inch or less is enough. The general rule to be followed is to ream all holes to standard sizes and to make all fits by varying the sizes of the inner pieces. Twist drills for drilling

holes that are to be reamed usually vary by $\frac{1}{64}$ inch in sizes up to 1 inch in diameter. Above 1 inch, they usually vary by $\frac{1}{32}$ inch, and sometimes by $\frac{1}{64}$ inch. If an allowance of $\frac{1}{64}$ or

Fig. 35

$\frac{1}{32}$ inch is considered too much to be removed by reaming, the drill may be ground so as to cut a hole slightly over its size.

48. Solid Taper Reamers.—Tapered holes for dowel pins and various other purposes have brought taper reamers into very general use. They are fluted and tapered, as shown in Fig. 35, which illustrates a solid taper reamer. The duty of a taper reamer is heavier than that of a straight reamer, as it must remove more metal. The drilled hole is straight and must be a little smaller than the small end of the reamed hole. The amount of metal that must be removed is represented by the part *a c b*, Fig. 36, and depends on the taper required.

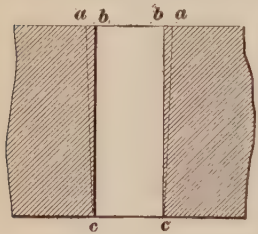


Fig. 36

49. Roughing Reamers.—If the taper is great, a roughing reamer, Fig. 37, is first used to remove the excess of metal. This is followed by a finishing reamer, Fig. 35, which should take only a very light finishing cut. In some shops, it is customary to relieve the reamer in heavy work by counterboring steps, as shown in Fig. 38, with drills of increasing sizes. This method,

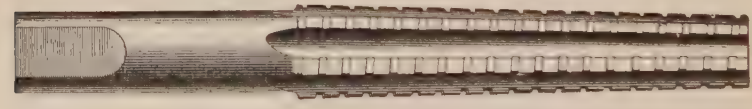


Fig. 37

however, takes much time, and it is better to use a stepped reamer, with which the metal can be removed more easily and rapidly than with drills.

50. Stepped Reamers.—A form of stepped reamer is shown in Fig. 39. The small end *a* is made the size of the drilled hole, and the edges *b*, *c*, *d*, and *e* of the lower ends of the steps form the cutting edges. The diameters are made from .002 to .003 inch less at the top of each step than at the bottom, to provide for clearance and to insure the free operation of the tool. There is also clearance on the bottom as shown at *f g*. This reamer should be followed by the notched roughing reamer shown in Fig. 37, to remove the steps and to enlarge the hole so that it can be completed with the reamer shown in Fig. 35. In holes of very slight taper, the stepped roughing reamer is not generally used, but even here, when a large number of holes are to be reamed, it may be used to advantage, as it preserves the cutting edges and the accuracy of the notched and finishing reamers. Stepped reamers to be used in ordinary drilling machines are made with taper shanks; but when they are to be employed in other kinds of machines they are made with squared shanks.

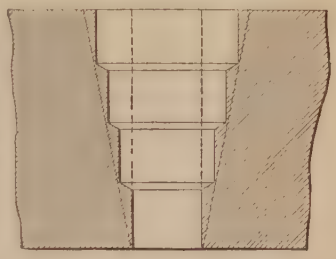


FIG. 38

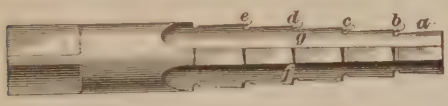


FIG. 39

51. Reamers With Inserted Blades.—The form of reamer illustrated in Fig. 40 has a series of inserted blades, or cutters, which are made of steel and are dovetailed into a solid

FIG. 40

body. In reamers 5 or 6 inches in diameter, the body is sometimes made of cast iron. The special advantages of this form are its cheapness and the ease with which a damaged blade may be renewed. In the solid reamer, a cracked or broken

cutting edge, or any slight warping may throw the whole reamer out of use; but in the inserted-blade type, the damaged cutter is simply driven out of the dovetail, a new one is inserted, and the reamer is as good as new. This is especially advantageous in the larger sizes, which are very expensive. Inserted blades are, however, not practicable in the smaller sizes, as there is not stock enough to support the blades properly. Opinion as to the smallest size in which they can safely be used varies; ordinarily, they are not used in reamers less than $1\frac{1}{4}$ inches in diameter.

52. Adjustable Reamers.—When a solid reamer is used, the diameter is generally made as much larger than the desired diameter as the limit of error in the working fit will allow, and it is used until the wear has reduced the diameter to the inside limit of error, after which it must be worked over or thrown away. For the best grades of machine work, where the allowable variation is very small, the life of a solid reamer is very short; hence,

FIG. 41

to provide a way of making allowance for wear, the adjustable reamer was produced. One type of adjustable reamer is shown in Fig. 41. It is adjusted to the desired size by means of a ground tapered plug that acts on the blades *a* and moves them outwards, thus causing the reamer to cut a larger hole. This plug may be locked by the locknut *b* when the adjustment has been made. With this type, a limited amount of wear or the reduction of diameter due to grinding can readily be taken up.

53. A reamer that is adjustable to allow for wear and also for different sizes of holes, within narrow limits, is shown in Fig. 42 (*a*). The blades *a* are L-shaped in section and rest in slots milled in the body of the reamer. Each is held in place by two or more setscrews *b*. A partial cross-section of the reamer, showing this method of holding the blades, is given in (*b*). The setscrew *b* has a beveled head that bears against a beveled face on the blade *a* and forces the latter firmly against

the bottom and side of the slot in the body *c*. Another form of blade is shown in (*c*), but the method of holding it is much like that just described. Thin liners of tin-foil, hard paper, sheet

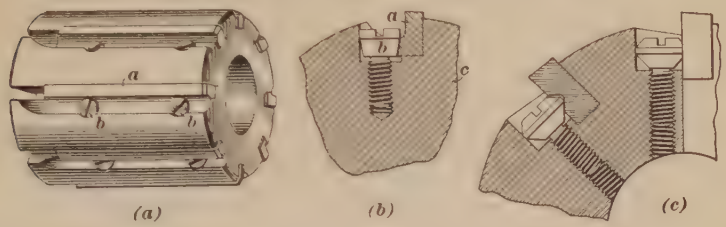


FIG. 42

steel, or brass may be placed under the blades in the slots so as to adjust the blades to cut the desired size of hole. Such liners should be free from dents or wrinkles.

54. Expansion Reamer.—Another form of adjustable reamer, known as the expansion reamer, is shown in Fig. 43. The reamer is drilled for a taper plug in the lower end, and the sides are slotted, as shown. The plug is threaded, and, when screwed into the end of the reamer, expands it. Reamers of this kind are made as small as $\frac{1}{4}$ inch in diameter, whereas the reamer illustrated in Fig. 41 is not made smaller than $\frac{3}{4}$ inch. The adjustment also is very easily made, and, by taking a number of cuts, a large quantity of metal may be removed. The hole is not at all accurate, however. The expanding plug enlarges the middle of the reamer most, and the cutting edges taper toward the ends, resulting in curved cutting edges without a straight part to guide them. Any unevenness in the structure of the metal as well as the act of reaming

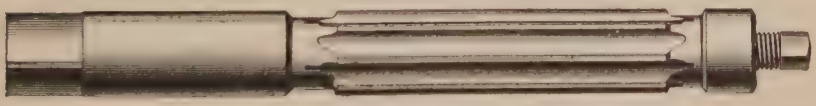


FIG. 43

causes the reamer to run out of its true course. Where accuracy is essential, this kind of reamer should never be used for the finishing cut.

55. Care of Reamers.—The most serious difficulty met with in reaming is the maintenance of the full diameter of the cutting edges, and in order to keep them in good condition as long as possible, the greatest care should be taken in their use. This is especially necessary with finishing reamers, which may be rendered useless by a very little wear or a slight injury. Reamers should never be pounded or jerked sidewise when in a hole, and when not in use, they should always be kept on wooden shelves or on some other wooden support.

COUNTERSINKS

56. Drill Used as Countersink.—The tools used in countersinking resemble the various forms of drills. In some shops and for some classes of work, the point of a drill is simply ground to the desired taper. When the cutting edges are properly formed, the metal uniform, and the surface square with the hole, fairly good results are obtained; but for general use it is better to have a countersink that is guided by a center guide.

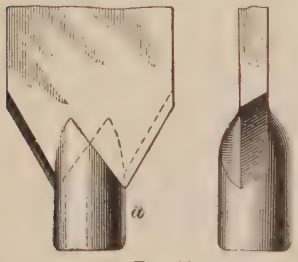


FIG. 44

57. Guide Countersink.—A flat countersink provided with a guide *a*, which fits the hole and holds the tool perfectly central under all conditions, is illustrated in Fig. 44. When used for flat-headed screws, this style of tool is usually made with an included angle of 72° and four cutting edges, as illustrated in Fig. 45.

58. Guide and Collar Countersink.—When a countersink of the same taper is occasionally required in holes of different diameters, a tool like that shown in Fig. 46 is found very serviceable. The guide *a*, instead of fitting the hole, becomes the bearing of a set of collars of different outside diameters, made to fit the different holes in which the tool is to be used. One of these collars is shown in place at *c*, where it is secured by a screw *b* and washer *d*. The cutting edges may be

made of any type desired, but four edges, as shown in the illustration, are perhaps the most desirable. There are enough cutting edges to guide the tool properly, and the construction

FIG. 45

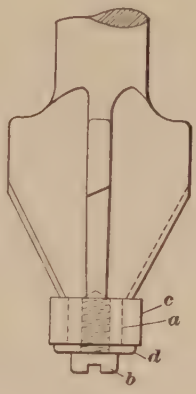


FIG. 46

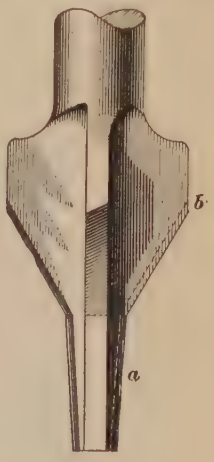


FIG. 47

is very simple. Turning the cutting edges back, as shown, forms a bearing for the top of the collar and makes the grinding easier. In some cases, collars are simply slipped over the guide of an ordinary countersink.

59. Combined Reamer and Countersink.—In plate work, reaming and countersinking may be done at the same time with the combination tool shown in Fig. 47. The lower end *a* is made like an ordinary fluted reamer and does the work of a reamer, and the countersink *b* is formed with four cutting edges ground to the desired angle.

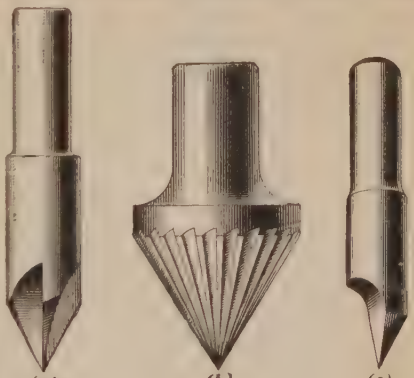


FIG. 48

60. Center Countersinks.—Fluted and half-round countersinks, as shown in Fig. 48 (*a*), (*b*), and (*c*), are used almost entirely in reaming centers in lathe work, but these styles may also be used for ordinary countersinking.

COUNTERBORES

61. Small Counterbore.—Small counterbores are made very much like the guide countersink just described, except that the cutting edges are set at right angles to the center line. A counterbore of this kind is shown in Fig. 49.

62. Double-Ended Cutter.—The counterbore shown in Fig. 50 is for large and special holes. It is made from a round

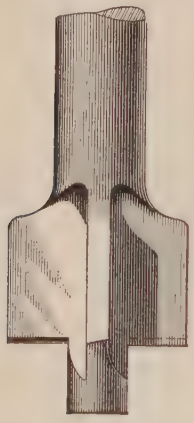


FIG. 49

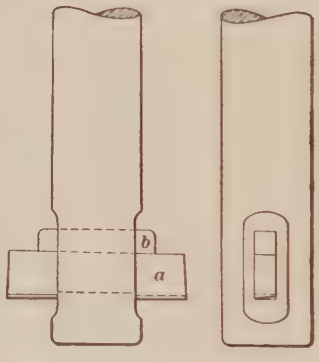


FIG. 50

bar of steel and has a taper shank. A rectangular hole is cut through it, in which a flat cutter *a* is inserted and held by a key *b*. The end of the bar is made to fit the hole without any play, while the length of the cutter represents the diameter of the counterbore. This cutter cuts on both ends, and great care must be taken to have it project the same distance on each side, and to have the cutting edges ground so that both sides will take equal depths of cut.

63. Counterbore for Light Work.—A useful tool for counterboring is illustrated in Fig. 51. A hole *a* is drilled in the bar *b*, in which a round piece of tool steel *c* is inserted and held in place by a pin *d*. The bar is then put in a lathe and the ends of the tool *c* are turned to the desired diameter. The ends are backed off and the cutting edges ground, as shown, flat on face and bottom. The lower end of the bar is turned to the diameter of the hole below the counterbore, to form a guide for the tool. This tool gives very good results when operated with care and on light cuts, but the cutter is not heavy enough to stand a very heavy strain.

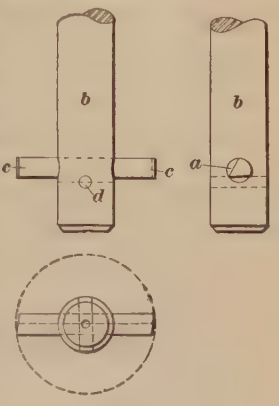


FIG. 51

64. Standard Counterbore.—Frequently, holes must be counterbored in two operations. For the fillister-head screw, for instance, one counterbore must be used for the head, and another for the body of the screw. In this case the counterbores are made in pairs and are of correct dimensions for standard screws. Such a pair is shown in Fig. 52, (*a*) being the counterbore for the head. The guide *a* is shaped to fit the hole made by the tap drill, and the counterbore *b* is constructed to cut the size of the screw head. The counterbore shown in (*b*) is used to counterbore for the body. Here, again, the guide *a* is made to fit the tap-drill hole, and the counterbore *b* has a diameter equal to that of the screw body. On the counterbores are spiral flutes making an angle of 15° or 20° with the axis. The guides, too, have flutes to

FIG. 52

make the sharpening easier and to allow the chips to fall out. If the body is counterbored first, it is necessary to use a third counterbore having a guide the size of the screw body.

65. Interchangeable Counterbores.—Counterbores are made in which guides and cutters of different sizes may be used with a standard holder. Such a form is shown in Fig. 53, in which (*a*) represents the several parts of the tool and (*b*) the assembled tool. The same letters are used to mark corresponding parts in both views. The shank *a* is tapered to fit the drill-

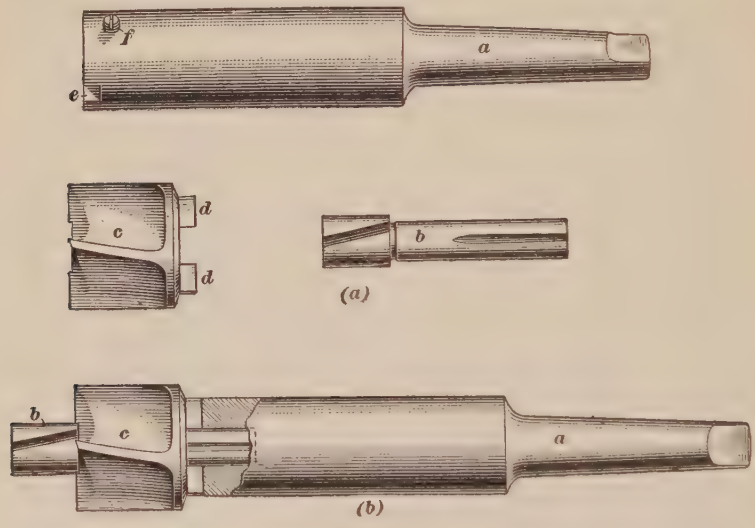


FIG. 53

press spindle and the lower end is bored out to take the guide pin *b*, which passes through the cutter *c*. The cutter has two tongues or lugs *d* that fit in a corresponding slot *e* across the bottom of the holder, and the cutter is thus driven. The guide pin is held in the holder by the setscrew *f*, and holds the cutter in place.

66. Undercutting.—Different methods are used to undercut the bottoms of holes so as to reduce the work of tapping. This operation is also sometimes called *bottom counterboring*. One form of tool for this purpose, known as the *Cleveland*

under-cutting tool, is shown in Fig. 54. The shank *a* must be smaller in diameter than the hole *b* to be undercut; and the difference in diameters must be twice the height of the thread on the tap that is to follow the undercutting tool. A cutter *c* is formed on one side, at the lower end, and the end *d* is made conical to fit the bottom of the drilled hole. The tool

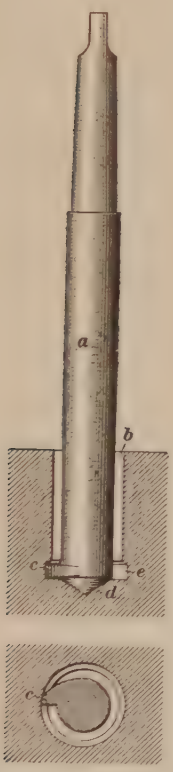


FIG. 54

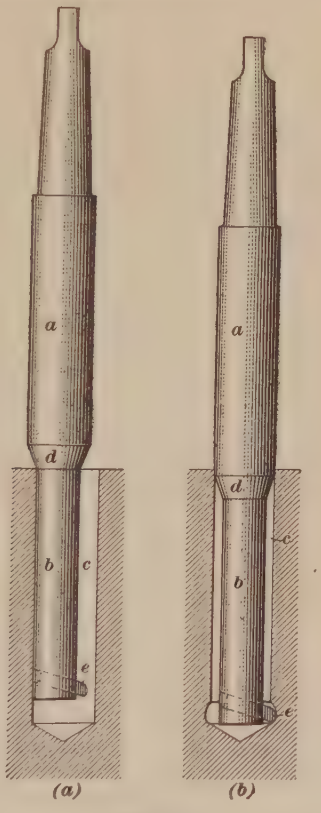


FIG. 55

is sprung to one side while the cutter is moved to the bottom of the hole. The machine is then started, and as the conical end *d* is pressed down into the conical bottom of the drilled hole by the down feed, the cutter is forced sidewise and the hole is undercut, as at *e*.

67. The undercutting tool ordinarily used in the shop is commonly made by turning a piece of steel to the shape shown in Fig. 55 (*a*), so that the upper end *a* has a diameter equal to that at the bottom of the thread of the tap to be used. The lower end *b* is made smaller than the drilled hole *c* by an amount equal to twice the height of the thread. The two parts *a* and *b* are joined by a short tapered part *d*, and a cutter *e* is driven into a hole drilled at an angle near the bottom end. The tool is inserted as shown, with the part *b* in contact with one side of the hole. As it is fed down, the tapered part *d* comes against the edge of the hole and gradually forces the cutter *e* over against the opposite side, causing it to undercut the hole. By the time the part *a* has entered the end of the hole, the bottom of the hole has been undercut as shown in (*b*).

SPOT-FACING OPERATIONS

68. Forms of Cutters.—The cutters used for spot facing are the same as those used for counterboring; the only difference in the operation lies in the depth of the cut. A counterbore may be of any depth, but spot facing is carried just deep enough to form a smooth bearing surface. The bar with an inserted cutter is especially well adapted to spot facing flanges of cylinders, cast-iron pipe flanges, etc.

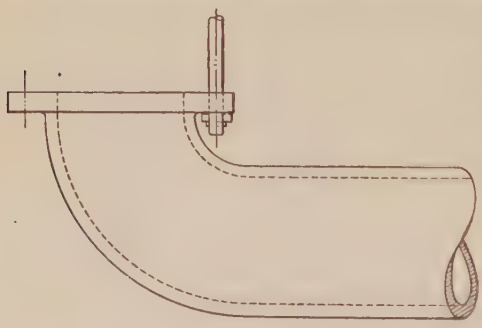


FIG. 56

69. Spot Facing the Under Side of a Flange.—A case in which an ordinary bar and cutter cannot be used for spot facing is shown in Fig. 56, in which the under face of the flange just above the inside bend must be spot-faced. The flange is drilled in the ordinary way, after which the drill is removed from the socket and the cutter bar is put in its place. The cutter

is then removed from the bar, the bar is passed through the hole, and a left-hand cutter is put in, with its cutting edges toward the flange. The spot facing is then done by feeding the drill spindle upwards, after securing the bar firmly in the spindle. This operation is slow, and should be used only when facing cannot be done in the usual way.

CENTER DRILLS AND TAPS

70. Center Drills.—The drills used for drilling center holes in the ends of pieces of work are short twist drills of small diameters, of the form shown in Fig. 57 (*a*). They are made short because they are used to drill only shallow holes, and also because shortness lessens the danger of breakage. Center reamers of the forms shown in (*b*) and (*c*) are then used to ream the drilled holes to the proper angle. The center hole may be

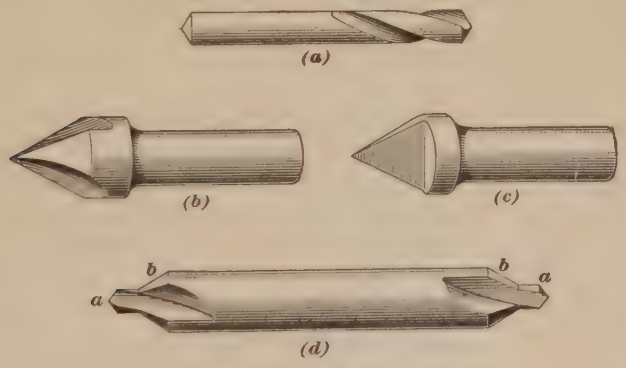


FIG. 57

formed in one operation by the use of a combination center drill and countersink like that shown in (*d*), which consists of a small twist drill *a* at the point and a countersink *b* just behind it. The tool is made double-ended as a matter of economy in the use of stock.

71. Taps.—The forms of taps used in drilling machines resemble hand taps. If the holes to be tapped do not run clear through the work, a *taper tap* must be used to start the thread

and a *plug tap* to complete it to a point near the bottom. When a full thread must be cut all the way to the bottom of a hole, the plug tap is followed by a *bottoming tap*. These three forms of taps are shown in Fig. 58. In the case of holes that pass through the material, the taper tap alone may be used. In high-speed machines, such as pneumatic drills, a long taper tap gives the best results, as less material is removed by each

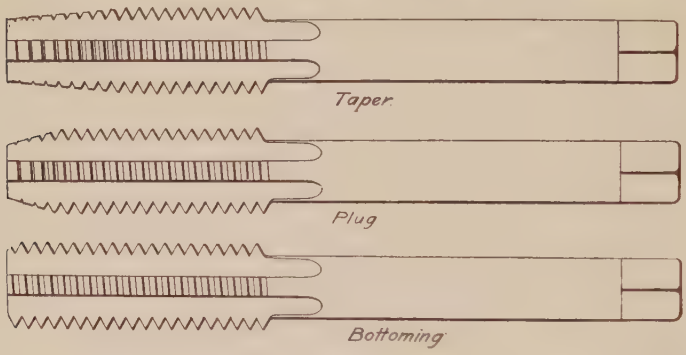


FIG. 58

tooth, the work being distributed along the length of the tap. Most machine tapping, however, is done by using the plug tap only. The shanks of taps that are to be employed in the drilling machine only may be made to fit the spindle of the machine for which they are intended. When they are required for general use, special sockets are needed to receive the square shanks of the taps.

HOLDING DEVICES FOR DRILLS

72. Straight Socket With Setscrew.—Various devices for holding tools in drilling-machine spindles have been brought into use. One of the earliest of these, which is still found in some shops, consists of a straight hole in the bottom of the spindle, with a setscrew to hold the drill, as shown in Fig. 59. The disadvantage of this form, however, is that a burr is formed on the drill by the pressure of the setscrew. This burr roughens the inside of the socket and makes the removal of the drill difficult. When the shank does not fill the socket completely, the

pressure of the setscrew on one side throws the drill off center in the spindle and results in the cramping of the drill and a poorly formed hole, and often in a damaged or broken drill. Also, the head of the setscrew is liable to injure the workman.

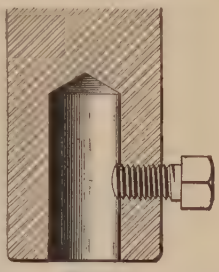


FIG. 59

73. Socket for Taper Shank.—A very simple and efficient means of holding a drill having a taper shank is shown in Fig. 60. The drill spindle *a* is made with a tapered hole *b* at the lower end. At the upper end, the hole is made flat on two sides to receive the tang, or flattened projection, on the upper end of the drill shank. The taper is just great enough to hold the drill when put in place with a quick motion of the hand or under slight pressure. The drill shank must, of course, be made with precisely the same taper as that in the spindle, so that both of the tapered surfaces will be in contact at all points. The drill is prevented from slipping in the spindle by the friction between the tapered surfaces and also by the tang; hence, the tang should fit fairly well. The drill is removed by driving a taper key *c* into the slot *d* in the spindle. The slot is so located that the point of the key just passes over the end of the tang, but when the body of the key is driven in, the drill is forced out.

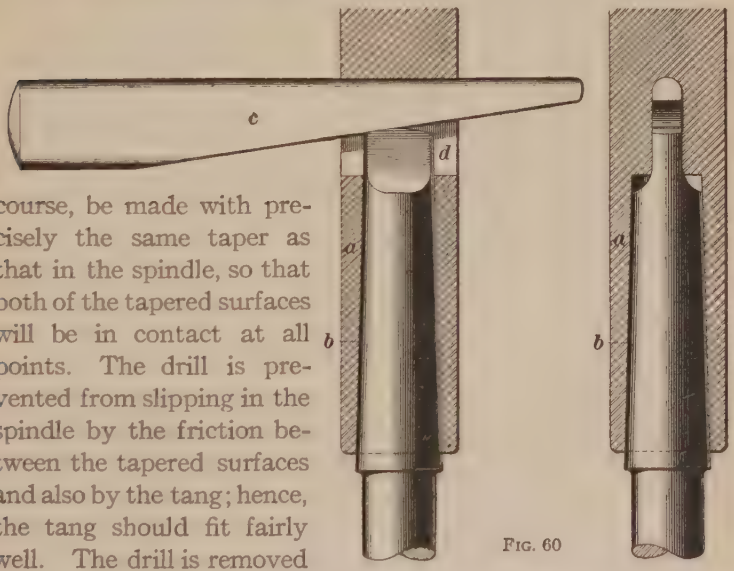


FIG. 60

74. Drill Sockets, or Collets.—All sizes of drills cannot be made with the same size of shank; consequently, it is necessary to have a number of drill sockets or collets, Fig. 61 (*a*) and (*b*), to take the sizes of drills that do not fit the spindle. The upper end of the socket is made to fit the spindle, or the next larger size of socket, and the lower end is made to fit the desired drill. Collets are also found very serviceable where it is desirable to use a drill with one kind of shank in a spindle intended for another. A collet for a taper-shank drill and a straight spindle is shown in (*c*).

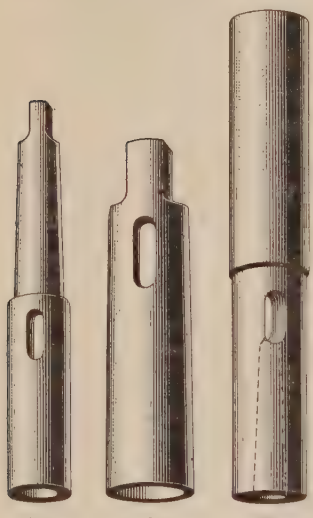


FIG. 61

75. Pin-Grip Socket.—A form of drill socket that allows the drill to be changed while the spindle is running is shown in Fig. 62. The shank of the socket *a* is made to fit the taper of the spindle *b*, and a collet *c* is made to fit over the shank of the drill *d*. The body of the socket *e* is bored out straight to receive the collet, which is held in place by two pins that enter the groove *f* and are controlled by the collar *g*. To remove the collet, the collar *g* is raised with one hand, while the drill is in motion, and the collet is removed with the other hand.

76. A partial section of the pin-grip socket is shown in Fig. 63. The collar *g* is bored out to form an internal cam. When the collar is in its lowest position, it holds the pins *h* in, as shown, their points entering the groove *f* in the collet. When the collar is raised to the position *i* indicated by the dotted lines, the rapid turning of the socket throws the pins out, thus releasing the collet. The ends of the pins are tapered, so that the weight of the collet or drill will assist in moving them out when the machine is running at a slow speed. The collar is brought back by its own weight when released by the hand. The collet *c* is

made with a tang j, which stands between the two pins k, thus causing it to rotate with the spindle.

77. Key-Grip Socket.—In very heavy work, the tang of the drill sometimes is twisted. Fig. 64 illustrates a device that grips the body of the shank as well as the end. The illustration shows the grip socket with a part cut away, thus exposing all the working parts. The shank and tang are of the

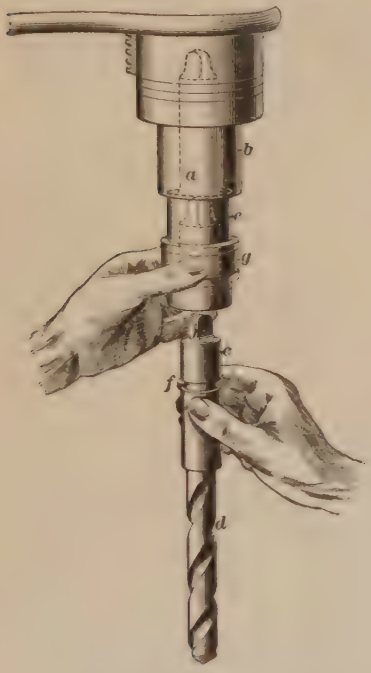


FIG. 62

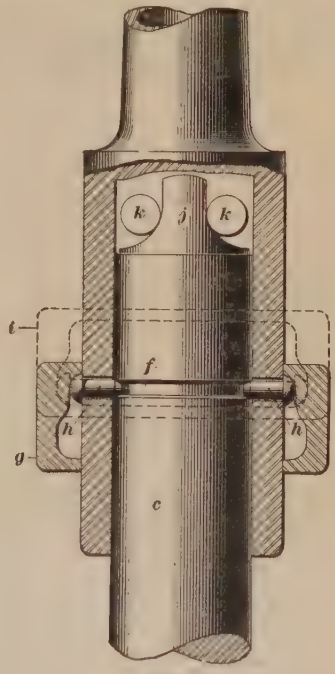


FIG. 63

ordinary taper type. A keyway a is cut in the shank of the drill with a circular cutter, thus making the bottom the arc of a circle. The key b, which fits the bottom of the keyway and also a slot in the socket, is held in place by a collar c that is bored eccentrically. When in the position shown, this collar causes the key to grip the shank and keeps it from working out, as well as prevents it from turning in the socket. To remove the drill, the collar is turned to a position where the key is free to move out

of the drill shank, and the drill is driven out in the usual way. This device can be used with any of the standard taper-shank drills by simply cutting the keyway.

A number of other designs of drill sockets are made; these include some form of key or driving device at the lower end of

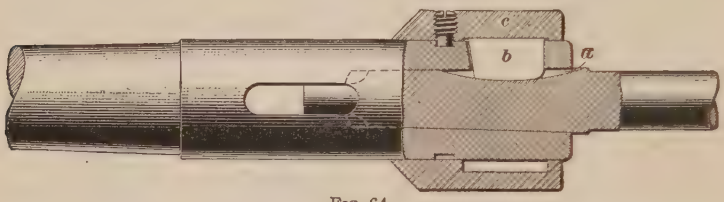


FIG. 64

the opening. This key enters a corresponding groove in the drill shank. There are also many special forms of high-speed drills and special methods of driving them.

78. Chuck for Small Drills.—Drill chucks that grip the drill shank at three or more points are used for the smaller drills. Fig. 65 (*a*) shows a type that is largely used. The body of the chuck *a* is held in the drill spindle by means of a taper shank.

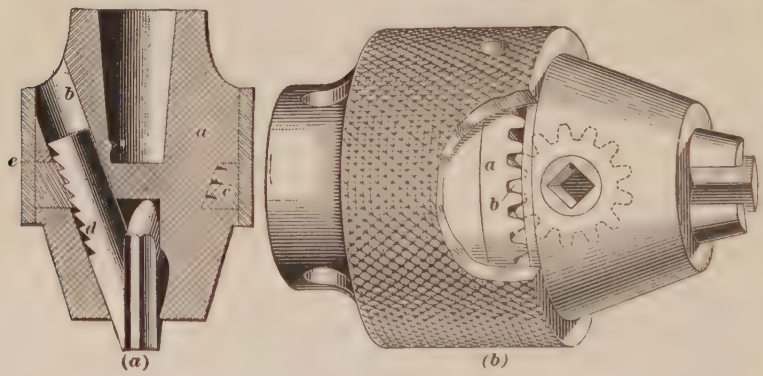
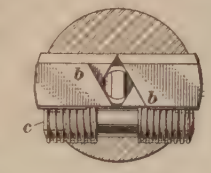


FIG. 65

In three holes *b* converging toward the center line, as shown, are three jaws *d*, which, when forced forwards by the nut *c*, close in on the drill shank and grip it firmly. The jaws are so formed that the parts that grip the drill are always parallel and therefore grip various sizes equally well.

79. The nut on the chuck in Fig. 65 (*a*) is held in and turned with the collar *e*, which is nurled on the outside to furnish a better grip for the hand. It is in two parts that are held in place in the chuck body by the collar, which is bored to a slight taper and driven over the nut. It is however, an easy running fit on the body. The chuck is taken apart by carefully driving off the tapered collar. One or more holes are drilled in the collar, so that a spanner can be used to tighten the chuck. A tighter grip on the drill can be obtained by the method shown in (*b*). Gear teeth are cut on the lower side of the nut *a*, and in mesh with these is the pinion *b*, which may be turned with a square-ended key or wrench.



80. Chuck for Heavy Drills.—A form of chuck that is used for heavier drills than the one just described is shown in Fig. 66. Across the lower end of the body of the chuck is cut a slot *a* in which two jaws *b* are free to move toward and away from the center. The jaws are controlled by means of a screw *c*, one end of which has a right-hand thread that engages with the thread on one jaw, and the other end a left-hand thread that engages with the other jaw. The jaws are so guided that the faces are always parallel, and drills of any diameter that will enter the chuck are gripped equally well. A hole in the plate *e*, which is screwed to the bottom of the body, is large enough to take only the largest diameter of drill for which the chuck is designed. A plate *f* just above the jaws contains a slot *g* made to fit the tang on the upper end of the drill shank, thus preventing the drill from slipping in the chuck.

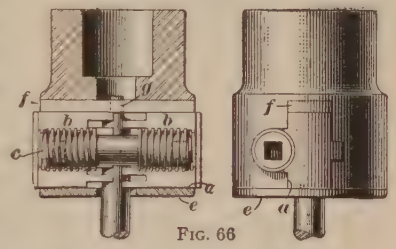


FIG. 66

81. Quick-Acting Roller Chuck.—A side view and a bottom view of a quick-acting automatic chuck are shown in

Fig. 67 (*a*) and (*b*). The drill *a* is held in the center of the chuck by three rollers *b*, each of which bears against a curved surface *c* formed on the inside face of the sleeve *d*. The curved surfaces are slanted, so that when the sleeve is twisted in one direction, they force the rollers inwards and grip the drill, and when it is twisted in the other direction, they release the drill. Drills may be changed in this chuck without stopping the drill press. The sleeve *d* is grasped firmly and held from turning; then the drill is removed, and another is inserted, after which the sleeve is released. A coiled spring inside the sleeve immediately acts on the sleeve and turns it so as to cause the rollers to grip the drill hard enough to hold it. When the drill begins to cut, the twisting tends to turn the sleeve still more, and grips the drill still more firmly.

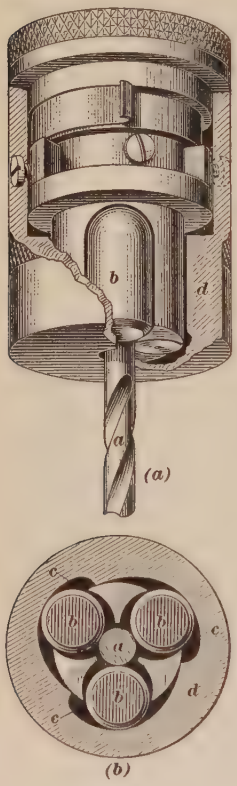


FIG. 67

82. Safety Drilling and Tapping Device.—A very efficient safety device for drilling and tapping is illustrated in Fig. 68. A shank *a*, which is tapered to fit the spindle with which it is to be used, has on its lower end an enlarged part that is threaded on the outside and bored out to form a friction seat for a socket *b*. A cap *c*, which has an internal thread to fit the external thread on the shank, clamps the socket between itself and the shank, forming another friction surface between the socket and the cap. Two fiber washers *d* and *e* are placed between the socket and the adjoining surfaces. The cap *c* is tightened on the washers until the friction obtained is sufficient to drive the drill or the tap, and is held in adjustment by the check-nut *h*.

83. Two spanner wrenches are required to make the adjustment of the device shown in Fig. 68. Drill and tap sockets that

fit the required drills or taps are made to fit the socket *b* and are kept from dropping out by the catch pin *l*, which enters the grooves *m* and *n* in the drill and tap sockets and is held in place by a spring and a retaining screw. The sockets are driven by means of two feathers. The tap shank is made about .01 inch smaller in diameter than the tap socket *f*, thus allowing the tap to take its own feed without injury to the thread, and to center itself with the hole without binding. A catch pin *o*, held in place by a flat spring, engages with a groove in the tap and keeps it from dropping out until a force greater than its own weight is applied. A specimen of the taps used, marked *i*, shows how the shank is constructed, *p* being the groove for the catch pin. The drill socket *g*, which is made in various sizes to take drills of different sizes, has a standard taper and a slot *j* at the upper end to receive the tang.

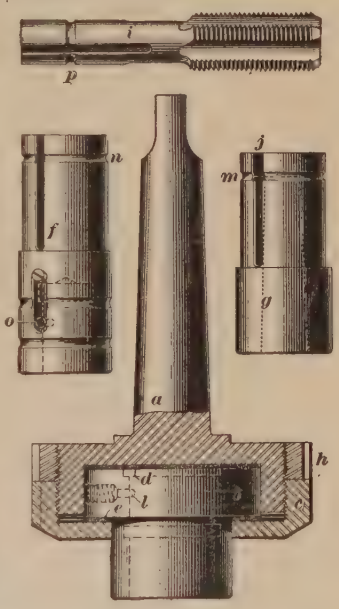


FIG. 68

84. Automatic-Reverse Tapping Chucks.—If a large amount of tapping is done, much time may be saved by the use of a device that will reverse the tap and back it out, either when the tap bottoms or sticks, or when it has run to the required depth. Several such devices are on the market and many of them give very good results. In one class, the mechanism is so designed that the tap travels with the spindle while running forwards, but as soon as it meets with more than a certain amount of resistance, a reversing gear, or set of gears, is thrown into action and the tap is backed out at an increased speed. In another class, the tap is also reversed and backed out when it has run to a stated depth. Such a device, it will be seen, insures safety and saves time.

HOLDING WORK FOR DRILLING

85. Drilling-Machine Table.—The table of the ordinary drill press should furnish a perfectly plane surface standing at right angles to the center line of the spindle. It should also be provided with holes through which bolts may be passed or with radial slots for T-headed bolts, so that work may be clamped rigidly on it. Securing the work properly on the table of a drilling machine is one of the important parts of drilling. A piece that is not properly set or not well secured will not be well drilled, although all other conditions may be perfect.

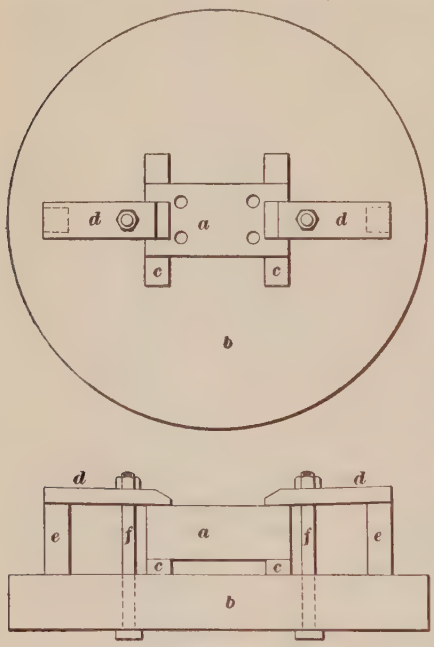
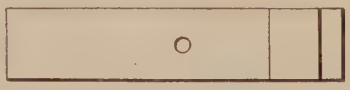


FIG. 69

86. Securing Work.—A plain piece of work, in which the holes are to be drilled at right angles to the face on which the piece rests, may be secured as shown in Fig. 69. The piece *a* to be drilled is laid on the table *b*, with two parallel pieces of iron *c* under it to raise it far enough from the table to prevent damage to the latter when the drill emerges from the piece. Two clamps *d* are then placed with one end of each on the piece over the parallels, and the other ends on blocks or screw jacks *e* of the same height as the top of the piece. Bolts *f* are then put through the clamps and the table, as near to the work as the holes will allow, and the nuts are screwed down until the clamps press firmly on the piece and hold it rigidly enough to prevent any slipping while the drill is passing through it.

87. The essential features of clamping are shown in Fig. 69. A piece must always be set so that the center line of the hole to be drilled is parallel to the center line of the spindle, and must be clamped rigidly in that position. Great care must be taken to have all the supports so adjusted that the piece will not spring out of shape when the clamps are tightened down. Irregular parts that have no flat surfaces on which to rest must be supported with jacks or blocks at different points. When pieces that are too large to be supported entirely on the table are to be drilled, the overhanging parts must be blocked up, to prevent any undue strain on the table or any spring in the piece itself.



88. Plain Clamp.—The clamps are often made by drilling a hole a little larger than the bolt in a piece of flat iron of suitable length. This kind of clamp is sometimes made with an offset, as shown in Fig. 70 (*a*), which serves the purpose of lowering the clamp-bolt nut so that it does not interfere with other parts, and allowing shorter bolts to be used.

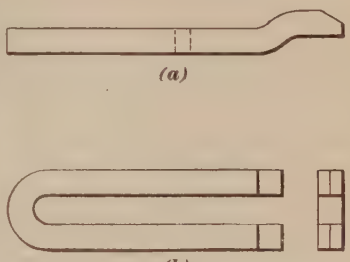
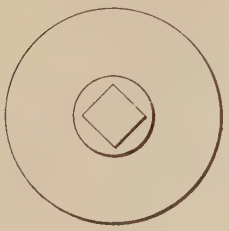


FIG. 70

89. U Clamp.—A more convenient clamp is made of a piece of square iron bent to the form of a **U**, as shown in Fig. 70 (*b*), the inside width being just great enough to take the bolt freely. Such a clamp can be removed and replaced without taking the nut off the bolt. In some cases, the other form is of advantage, however, and both are found among the accessories of a drilling machine. The **U** clamp is often made without the offset at the end, shown in the illustration.

90. Screw Jack.—The screw jack consists of a cast-iron foot *a*, Fig. 71, which has a tapped hole running vertically through it and a square-headed bolt *b*, with a thread cut the entire length of the body, screwed into it. The top of the

bolthead should be faced to form a good bearing surface, and the corners rounded to prevent any digging when adjusting the height. The bottom of the foot is sometimes left rough, but it is better to have it finished.



91. Parallels.—The parallels used in blocking up the work should be carefully planed and should be made of rectangular

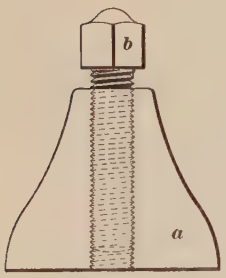


Fig. 71

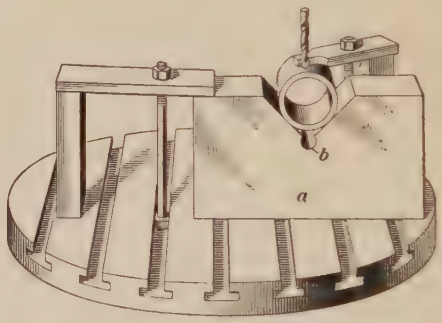


Fig. 72

cross-section and in pairs. Sometimes parallels are made with the width exactly twice the thickness. It is convenient to have the width of each pair equal to the thickness of the next larger pair.

92. V Blocks.—Cylindrical parts are usually supported on V blocks, as shown at *a*, Fig. 72. The V blocks should be made in pairs, so that a piece resting on them may be exactly parallel to the drill table. It is usually of advantage to make the block wide enough to support short pieces with a single clamp, as shown. A hole *b* drilled at the point of the V will form a

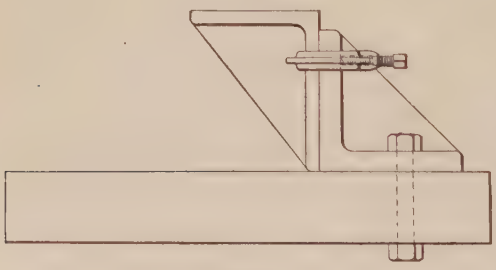


Fig. 73

clearance in planing. The two sides of the V usually make an angle of 90° with each other.

93. Angle Plates.—A piece with a flat surface at right angles to the surface to be drilled is usually attached to an angle plate by means of clamps, as shown in Fig. 73. If the overhanging part is too long, it should be blocked or jacked up and clamped at another point as far away from the angle plate as possible. The angle plate must, of course, be firmly bolted to the table. Angular pieces are frequently supported on angle plates of the same inclination as the pieces. For instance, the piece *a* in Fig. 74 is clamped to an angle plate *b* of the same inclination, thus bringing the surface to be drilled parallel to the table.

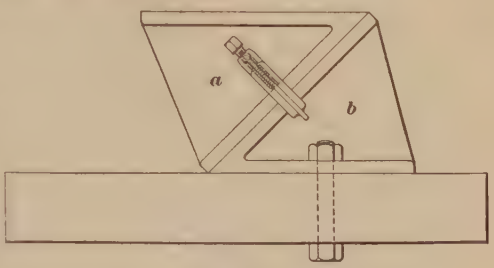


FIG. 74

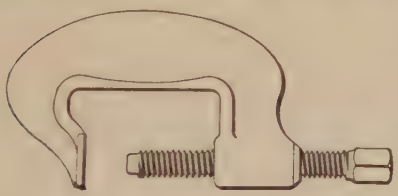


FIG. 75

94. C Clamp.—The style of clamp shown in Fig. 73 is known as a C clamp and is shown on a larger scale in Fig. 75.

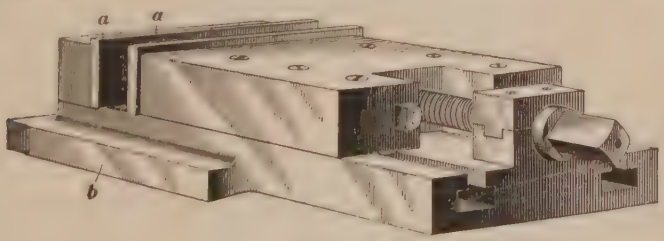


FIG. 76

95. Vise.—A vise as shown in Fig. 76 is often used for supporting the work. It is especially convenient where the

bottom of a piece is irregular and yet has parallel sides that the vise may grip between the jaws *a*. A lug *b* on each side forms a convenient means of clamping the vise to the table.

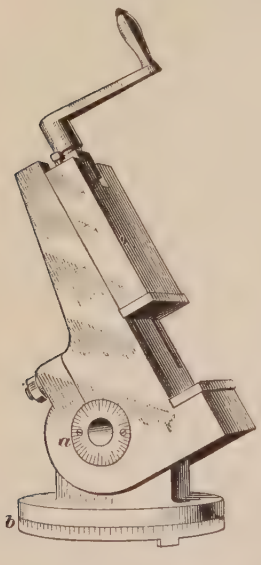


FIG. 77

96. Universal Vise.—A universal vise that may be bolted to the table of a drilling machine and may be rotated both in a horizontal and in a vertical direction is shown in Fig. 77. The two circles *a* and *b* are graduated, as shown. Such a vise is especially useful where holes must be drilled at different angles in the same piece. The piece can be set either horizontally or vertically, and, by having the circles graduated, it can be rotated to any desired angle without resetting.

97. Drilling Parts Together. When two adjoining pieces are to be drilled so that the holes in the two are to match perfectly, they should be drilled together whenever practicable. This insures a perfectly continuous hole, and avoids a great deal of awkward and expensive fitting.

DRILLING
(PART 2)

DRILLING MACHINES

CONSTRUCTION AND OPERATION

DRILLS FOR MEDIUM WORK

1. Kinds of Drilling Machines.—The drilling machines most commonly used in the machine shop are classed as drill presses, radial drills, column or post drills, horizontal drills, traveling-head drills, gang or multiple-spindle drills, sensitive drills, and portable drills. There are also a number of kinds of special drills. Drilling machines used for ordinary work are usually made so that the work is held stationary during the drilling operation while the tool is rotated as it is fed into the work. Sometimes, however, the work is rotated and the tool is fed down into it without turning.

2. Heavy Drill-Press.—A form of drill press that is used on a large variety of work is shown in Fig. 1. As the column *a* forms the main part of the machine, it must be stiff enough to prevent springing during drilling. It is held upright by a heavy floor plate *b* that is used also as a support for large work. An arm *c* is carefully fitted on the lower part of the column and carries a table *d* on which small work is held for drilling. The arm may be swung around the column; also, it may be moved up or down by turning the handle *e*, which drives

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a small pinion that meshes with the rack *f*. The rack is free to slide around the column as the arm is swung, but it is prevented from moving up or down by the shoulders between which it fits. The table can be turned on the pin by which it is held in the end of the arm. Both the table and the arm may be locked in position by tightening the clamping screws.

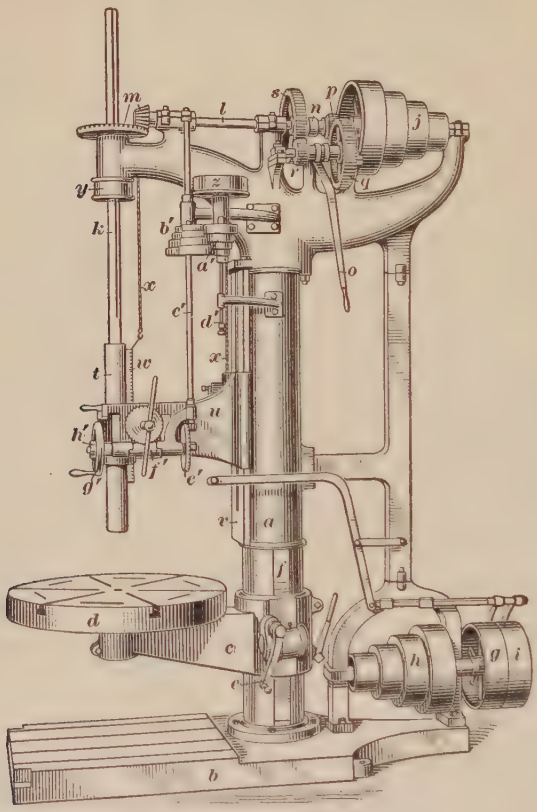

FIG. 1

3. Driving of Drill Press.—The drill press shown in Fig. 1 is driven from a countershaft or a line shaft by a belt that runs on the pulley *g*, which is fastened to the same shaft as the cone pulley *h*. This belt is shifted to the loose pulley *i* when the drill is to be stopped. From the cone *h* a belt runs to the

similar cone *j* at the top. When the belt is on the largest pulley of the lower cone and the smallest pulley of the upper cone, the drill has its greatest speed; and when the belt is on the smallest pulley of the lower cone and the largest pulley of the upper cone, the drill has its least speed. The upper cone drives the spindle *k* through a short horizontal shaft *l* and the bevel gears *m*.

4. Back Gearing of Drill Press.—The driving shaft *l*, Fig. 1, is made in two parts that may be connected or disconnected by moving the clutch *n* by means of the handle *o*. A small gear *p* is fastened to the driving shaft near the cone pulley and meshes with the large back gear *q*, which thus turns at a slower speed than the gear *p*. The back gear *q* is fixed on a quill, or sleeve, that has a small gear *r* at its other end, and the gear *r* meshes with a gear *s* on the shaft *l*. The back gears *q* and *r* can be shifted along the shaft on which the quill turns, and may thus be thrown out of mesh with the gears *p* and *s*. The handle *o* is so arranged that when the clutch *n* is thrown into action, the back gears are thrown out of mesh; and when the clutch is thrown out of action, the back gears are moved into mesh. When the back gearing is in mesh, the drill spindle is driven slowly but with great force.

5. Drill-Press Spindle and Head.—The lower end of the spindle *k*, Fig. 1, rotates inside the cast-iron sleeve *t*, which passes through a hole bored in the outer end of the head *u*. The head may be moved up or down on the slide *v*, and its purpose is to steady the end of the spindle. The cast-iron sleeve *t* has a rack *w* at one side, by which it may be moved upwards or downwards, carrying the spindle with it, and thus giving the feed to the drill. The upper end of the spindle has a keyway cut in it, to fit a feather set in the hub of the larger of the bevel gears *m*. Thus, the spindle is driven when the bevel gear turns, but may move up and down in the gear when the sleeve *t* is raised and lowered. A tapered hole is bored in the lower end of the spindle to receive the drill shank. The chains *x* attached to the sleeve and to the head pass over pulleys, and run down inside the column *a*, where counterweights are hung. The sleeve and the head are thus counterbalanced and may be raised easily.

6. Feed-Mechanism of Drill Press.—The feed of the drill press shown in Fig. 1 is obtained from the pulley y. A belt runs from this pulley to the pulley z, which drives a set of gears a' that mesh with a corresponding set b' on the vertical shaft c'. The gears in each set are of different sizes, and by moving the rod d', the pulley z can be made to drive the shaft c' through any one of the four pairs, thus enabling the shaft c' to be turned at different speeds. The shaft c' has at its lower end, a bevel pinion that drives a bevel gear e' on the worm-shaft f', and the worm on the worm-shaft drives a pinion that meshes with the rack w. In this way the downward feed of the spindle may be varied to suit the work. The drill may be fed by hand by turning the hand wheel g'. Power feed is obtained when the bevel gear e' is clamped to the worm-shaft by tightening the nurled nut h'.

HIGH-SPEED DRILLS

7. Carbon Steel and Alloy Steel.—The two kinds of steel used for drills are carbon steel and alloy steel, the latter being also called high-speed steel. Carbon steel suitable for drills contains about $1\frac{1}{4}$ per cent. of carbon, and drills made from it are hardened by being heated to a cherry red and then dipped endwise into cold water, brine, or a special hardening bath. Alloy, or high-speed, steel contains different percentages of one or more of the substances manganese, chromium, nickel, tungsten, or vanadium. It is not injured by the temperatures to which a cutting tool is heated, and drills made of it are hardened by being heated to a white heat and then cooled by a blast of air. Drills made of alloy steel can be run at from two to three times the speed of carbon-steel drills of the same size.

8. Ball-Bearing Drill Spindle.—The ordinary type of drill spindle is in direct contact with the sleeve in which it turns, and there is considerable friction between the two parts. This friction is greatly increased if the lubrication is poor or if the parts are badly adjusted. Tests on ordinary machines driven by $1\frac{1}{4}$-inch belts showed that the limit of the capacity

of the machines was reached when a $\frac{3}{8}$-inch carbon-steel drill was used; but when ball bearings were used, instead of plain bearings, on the spindle, a $\frac{3}{4}$-inch high-speed drill could be employed. As a result of these tests, a class of light drills with ball bearings has been made for use at high speeds.

RADIAL DRILLS

9. Simple Radial Drill.—A machine that is designed for a class of work that cannot well be mounted upon a drill-press table, either because of its size or weight, is shown in Fig. 2 and

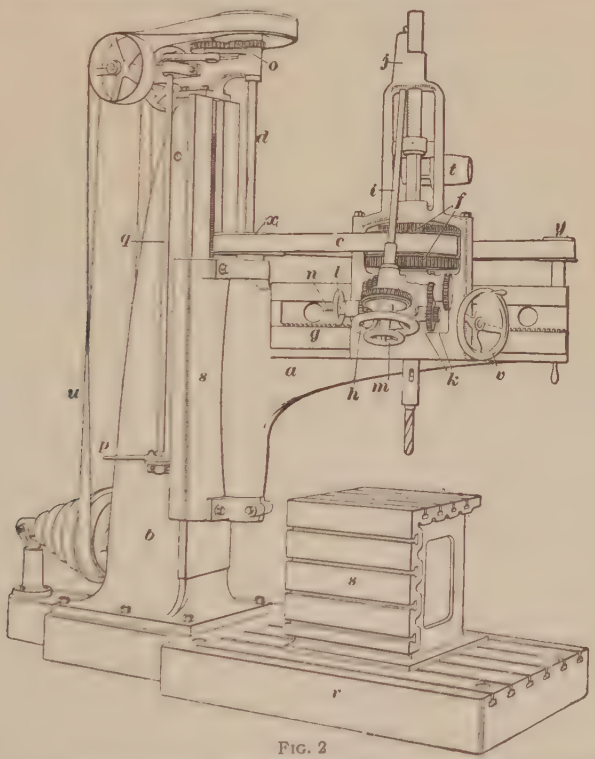

FIG. 2

is called a radial drill. The spindle is carried in a head that traverses back and forth on a radial arm *a*, which is hinged on a vertical slide *s* on the column *b*. The spindle is driven

by a belt c that runs over the pulley x on the shaft d and over the pulley y on the end of the arm. An intermediate pulley that travels with the head, and about which the belt is carried by means of an idler, transmits the motion to the spindle. The plan view of the belt c is shown in Fig. 3. The driving pulley x is splined upon the shaft d, and the pulley y is supported on the outer end of the arm a; z represents the driving pulley on the drilling head, and w represents the idler. The motion is transmitted either to the spindle direct or through back gears shown at f, Fig. 2. A counterweight t balances the weight of the spindle, thus relieving the feeding device. The head is traversed by means of a hand wheel v, which has a worm on the other end of its shaft engaging with the rack g.

10. Both hand feed and power feed are provided on the drill shown in Fig. 2. The former is operated by the hand wheel h on the shaft i, which has on its end a worm at j that engages with a rack on the upper end of the spindle. The power feed is obtained by means of a worm on the spindle running in a worm-gear, and is connected with the shaft i by means of the gears, worm, and worm-gear at k. Either the hand feed or the power feed is thrown in as desired by means of the hand wheels l and m and the pin n.

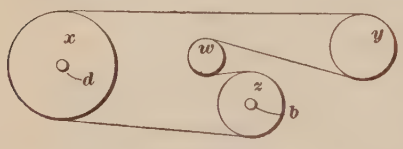

FIG. 3

In the larger sizes of this type of machine, a power traverse for the head is also furnished, taking its power from a screw in the radial arm a, which is connected with the vertical shaft d by a pair of bevel gears. The arm a and the slide s are raised by a screw in the column that runs in a nut attached to the slide between the guides of the upright. The power is transmitted to this screw through the gearing at o, and is controlled by the handle p on the lower end of the vertical rod q.

11. The work for which the radial drill is used is usually large and is generally supported on the foot-plate r, Fig. 2, which is finished and fitted with slots for T-head bolts. The table s is, however, provided for smaller pieces, or pieces that require

side support. It is finished and has slots for supporting work on the top and sides. For light work, its own weight is sufficient to hold it in place, but for very heavy cuts, or where there is a tendency to tip, it should be bolted down. The work must always be so set that there will be no spring in the piece when the clamps are tightened, and should be so placed that as much work as possible may be done without resetting.

12. Gear-Driven Radial Drill.—The radial drill is often driven by shafts and gears instead of by belts. The power is transmitted directly from the main driving cone to a vertical shaft in the center of the column, and then, by means of gears at the top of the column, to a vertical shaft corresponding to *d*, Fig. 2. Another pair of bevel gears connect this shaft with a horizontal shaft on the radial arm, and the latter shaft in turn is geared to the spindle in the drilling head.

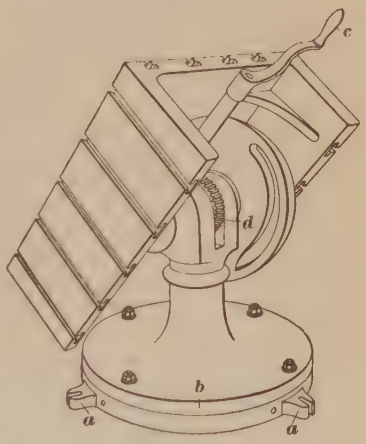

FIG. 4

13. Universal Table. The universal table, shown in Fig. 4, may be used on a radial drill to hold small pieces in which holes must be drilled at an angle. The table is bolted to the foot-plate by the lugs *a*, and may be turned about its center on the circle *b*. The top can be set at an angle, as shown, by turning the handle *c*, which drives a worm that meshes with the worm-gear *d*. Clamping bolts on each circle hold the table firmly in place when it has been adjusted to a desired position.

14. Universal Radial Drill.—Large work that cannot be supported on a universal table is drilled on a radial drill having an arm that can be rotated about its own center, and that is equipped with a head that can be thrown to any angle, as shown in Fig. 5. The rotation of the arm is obtained by

pivoting it on the center of the shaft *c*. Such a machine is called a universal radial drill. The circle *a* on which the arm is rotated is graduated in degrees, and, as the arm may be turned through the entire circle, an adjustment to any angle may be made quickly and accurately. The circle *b* on the head is also graduated, thus furnishing a ready means of setting the spindle to any required angle. This machine differs in some details

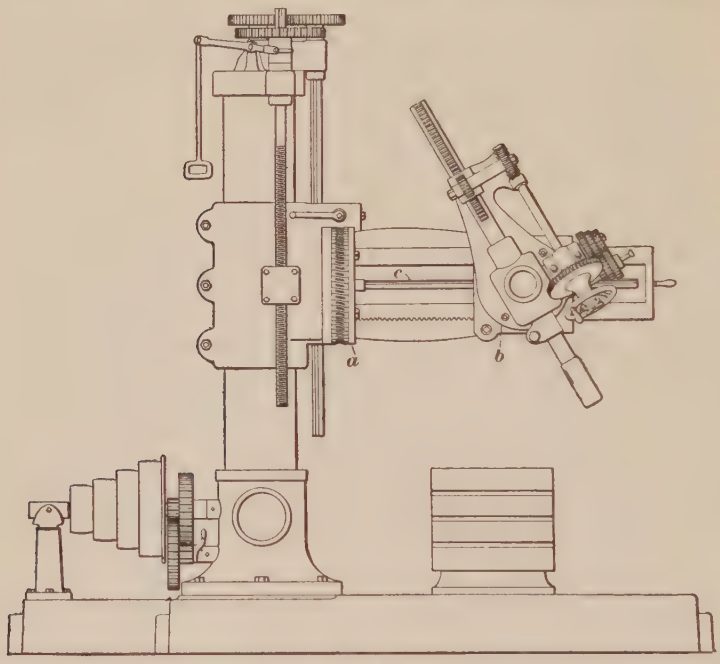

FIG. 5

from the radial drills already described, but it has the same general construction.

15. Change-Speed Gear-Box.—The speed of a drill spindle may be altered by using a gear-box, as shown in Fig. 6. The gear-box consists of a casing *a* containing a set of change-speed gears, and is bolted to the base *b* of the drill. A belt drives the pulley *c*, and the coupling *d* connects the gear-box to the driving shaft of the machine. The speed is changed by

shifting the handle e up or down along the series of steps formed along the open side of the gear-box. When the gears are set

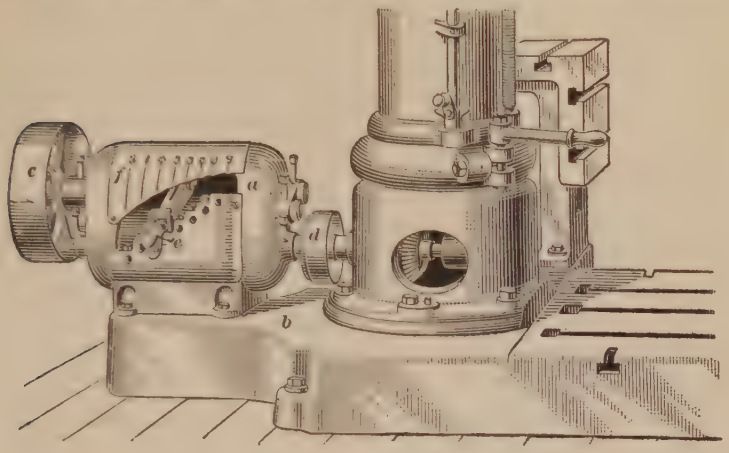

FIG. 6

for a given speed, the handle is held in place by a pin that fits a corresponding hole just below the step. In the gear-box

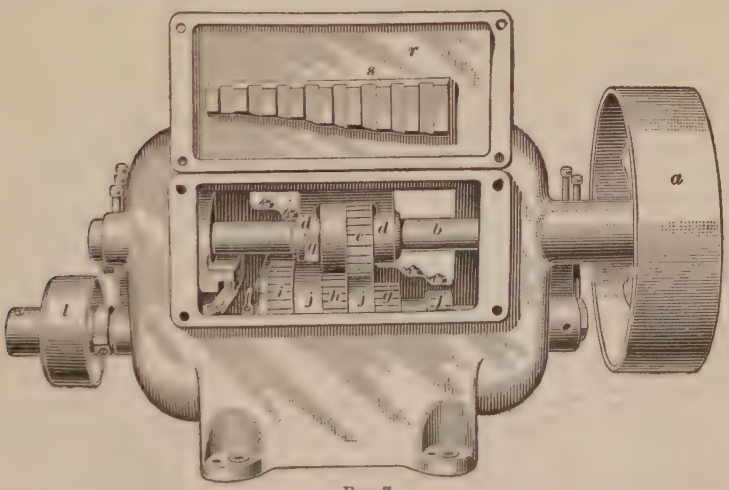

FIG. 7

shown, eight different speeds may be obtained. The positions of the handle for these speeds are numbered from 1 to 8, as

shown on the plate *f*, the speed being greatest at position *1* and least at position *8*.

16. A back view of the gear-box, with the back cover removed, is shown in Fig. 7, and in Fig. 8 (*a*) and (*b*) are shown diagrams of the gear-arrangement as seen from the front and the end of the gear-box. The views in Fig. 8 do not give the actual shapes and proportions of the parts, but are merely intended to show the principle on which the gear-box acts. Those corresponding parts that can be seen in both Figs. 7 and 8 are given the same reference letters. The pulley *a* is fixed to a shaft *b* that runs from end to end of the gear-box. A pinion *c* is splined to the shaft, so that it can move freely along the shaft but must turn when the shaft turns. This pinion is held between the jaws *d* that form the upper end of the handle *e* by which the changes of speed are made. These jaws can both turn and slide on the shaft *b*.

17. In the lower part of the gear-box, Figs. 7 and 8, is a series of gears *f*, *g*, *h*, and *i* separated by blanks *j* and forming a cone. These gears are fixed on the shaft *k* that is connected by the coupling *l* to the driving shaft of the drill. The handle *e* near its middle carries a compound pinion consisting of two small gears *m* and *n* firmly fastened together. These gears are of different sizes and are fast to a shaft *o* that turns in bearings in the handle *e*. The smaller gear *n* of the compound pinion is always in mesh with the pinion *c* on the shaft *b*, and when the handle *e* is lifted and moved, the compound pinion and the pinion *c* are shifted in the same direction and at the same time. By shifting the handle sidewise in the slot in the front of the gear-box, the gear *m* or *n* of the compound pinion may be engaged with any one of the gears *f*, *g*, *h*, and *i*, and thus eight different speeds may be obtained.

18. In the position shown in Fig. 8, the gear-box is set for the greatest speed, corresponding to position *1* on the plate *f*, Fig. 6. The pinion *m*, Fig. 8, is in mesh with the gear *f* and the shaft *k* is driven at the greatest speed that can be obtained with this gear-box. If the handle is moved one step to the left, the

pinion n will engage with the gear f and the shaft k will turn slower. If the handle is shifted one step to the right from the position shown, the pinion n will mesh with the gear g and a still slower speed will result, because the gear g is larger than the gear f. To make certain that the gears are in the correct posi-

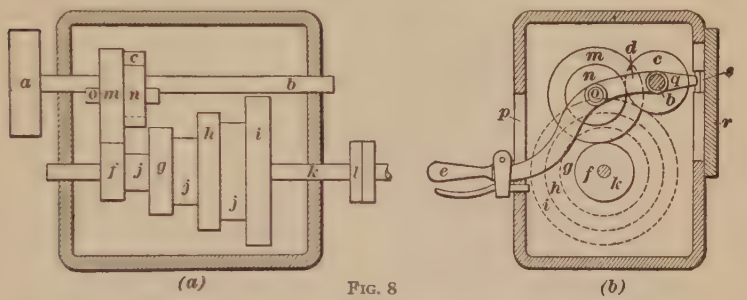

FIG. 8

tion to engage properly, the handle has a projecting toe q at the back, and on the back cover-plate r is a rack s with eight slots. The handle cannot be lowered to engage the gears until the toe q is directly opposite one of these slots. The toe, the rack, and the slots are clearly shown in Fig. 7, also.

SENSITIVE DRILLS

19. Construction of Sensitive Drill.—In a machine shop, there is a large amount of light work on which it is necessary to use drills that are too small to be run at the required speeds in heavy drilling machines. This has led to the development of a light and sensitive type of drilling machine called the sensitive drill, one form of which is shown in Fig. 9. The power is transmitted directly to the spindle by belts, and the speed is varied by the use of cone pulleys. The feed is obtained by hand by turning the lever or bar at the outer end of the head c. The lever is fixed to a shaft that carries a pinion that meshes with a rack cut in the sleeve of the spindle. This is the most sensitive arrangement in use, any variation in the working conditions of the drill point being readily felt by the hand on the lever. The table a of the drill shown has no vertical adjustment,

but may be swung about the center of the post, out of the way of the center line of the spindle, so as to allow long pieces to be set on the lower table *b*. The lower table and the lower spindle head *c* are both adjustable vertically, thus allowing pieces of greatly varying lengths to be drilled in the machine.

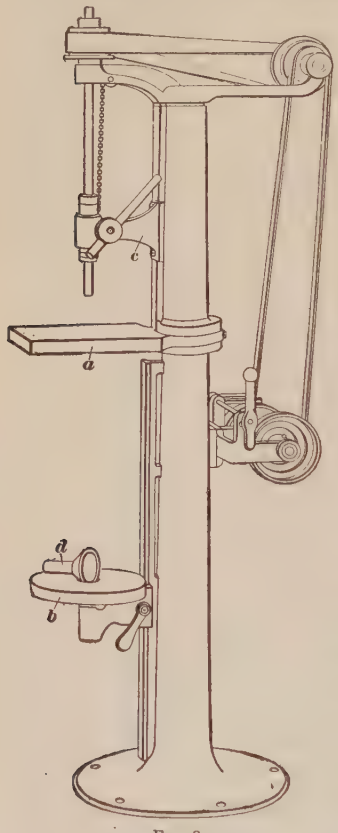

FIG. 9

20. Center Drilling With Sensitive Drill.—The sensitive drill is used largely for center drilling in shops where a special machine for this purpose is not available. The funnel-shaped piece *d*, Fig. 9, commonly called a *cup center*, is a special device for centering the lower end of a shaft that has been cut off square. The shank is set in a hole in the center of the lower table *b*, the center line of which coincides with the center line of the spindle. The top of the cup *d* is made a perfect internal cone, with its axis in the center of rotation of the spindle. A shaft that is set in this cup and is held with its center under the drill at the upper end will, therefore, be correctly centered.

21. Sensitive Radial Drill.—The larger sensitive radial drill has been brought into use to provide a simple machine that can be operated quickly and easily on work too large for the sensitive drill and too small to be done economically on the drill press or the large radial drill. It is designed to give the required speed for the smallest drills and to have power and stiffness enough to drill holes $\frac{3}{4}$ inch in diameter. The form shown in Fig. 10 consists of a floor plate *a* that carries the

column *b* and the bracket to support the driving pulley *c* and the loose pulley *d*. The column carries the radial arm *e* at the top and the work table *f* at the middle. The rack *g* fits in a slot in the table and is held between shoulders on the column, so that

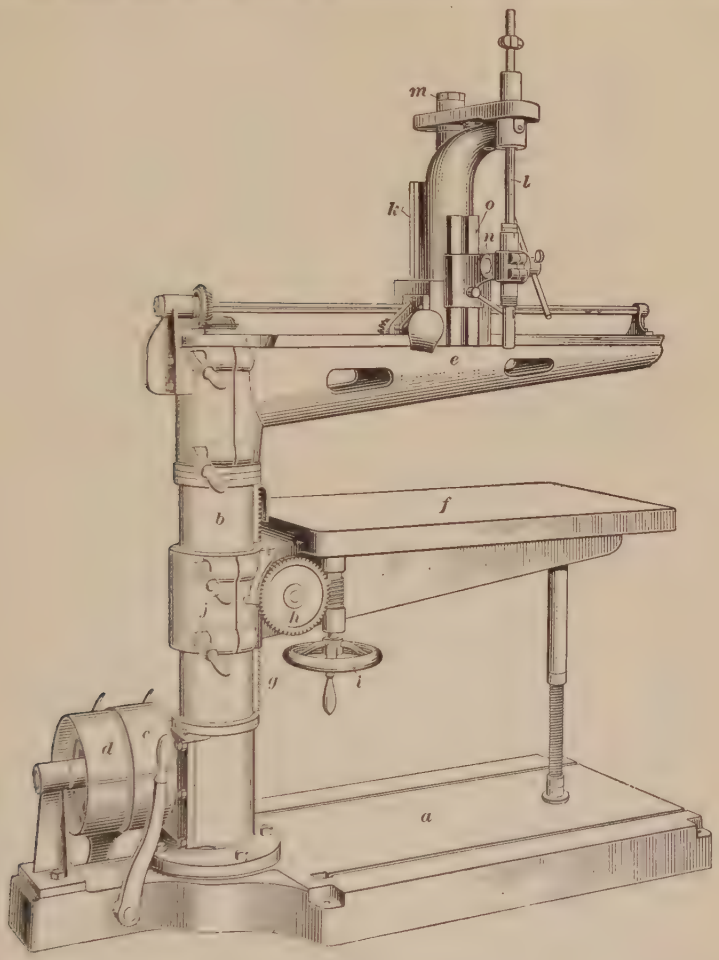

FIG. 10

it can swing around the column with the table but cannot move up or down. The rack meshes with a pinion on the same shaft as the worm-wheel *h*, and when the hand wheel *i* is turned, the

table is raised or lowered. The handles *j* are turned to clamp the table tightly on the column, and similar handles are used to clamp the radial arm to the column. The drilling head *k* may be moved along the slide on top of the arm *e* and clamped at any point. The spindle *l* is driven by belt or by chain from the shaft *m*, which is connected by bevel gears and shafts to the driving pulley. The drill-spindle arm *n* is adjustable vertically on the slide *o*. If desired, the table may be swung to one side, and the work may be secured to the floor plate by T bolts in the slots shown.

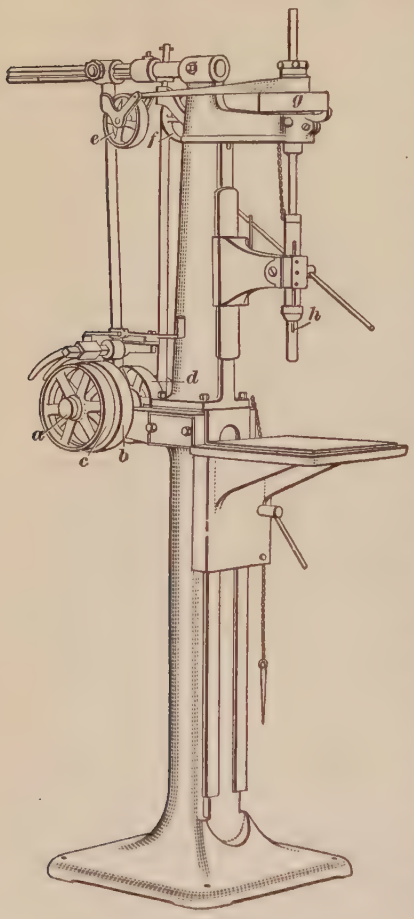

FIG. 11

22. High-Speed Sensitive Drill.—A high-speed sensitive drill with ball bearings on the spindle is shown in Fig. 11. The driving shaft *a* carries the tight and loose pulleys *b* and *c* at one end and the cone pulley *d* at the other. This cone pulley has two steps and from it a belt passes over the adjustable guide pulleys *e* and *f* to a similar cone pulley *g* of different size on the spindle *h*. Thus, by arranging the belt on different pulleys, four different speeds of the spindle may be obtained. The pulleys *b* and *c* are of slightly different sizes and the loose pulley *c* is made with one edge beveled outwards to the diameter of the tight pulley. Thus, when the

belt is running on the loose pulley, it is slack, and therefore does not wear much or stretch; but when it is shifted to the tight pulley, it is stretched and grips the pulley, thus insuring little slip and good driving power. The same construction is used in Fig. 10.

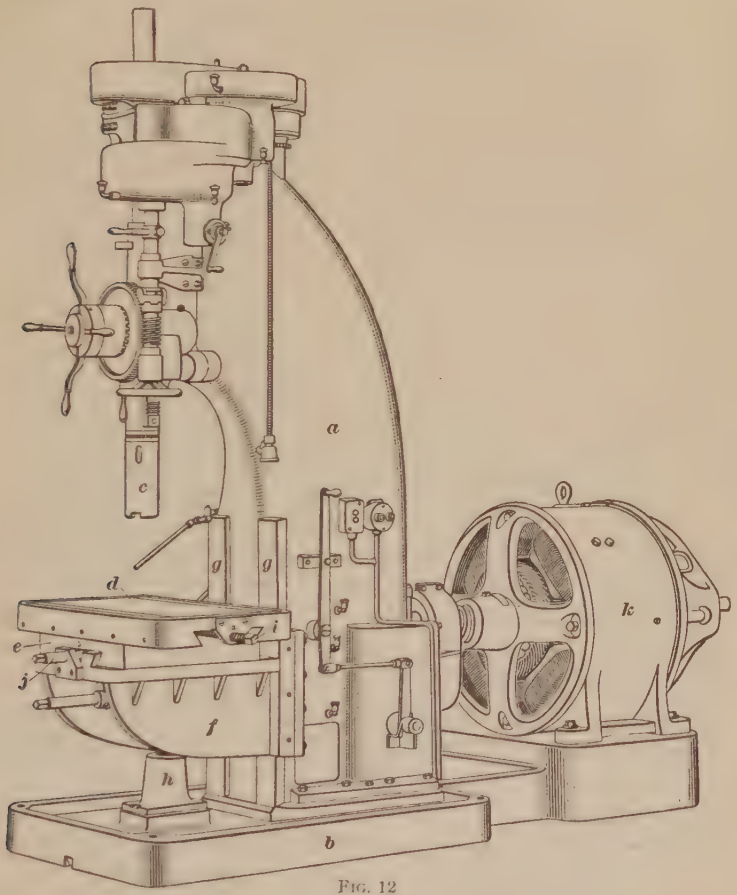

FIG. 12

23. Heavy-Duty High-Speed Drill.—Drilling machines of the older types could not be used to advantage at high speeds because of the vibrations set up and also because they would spring under the pressure of the heavy feeds when using alloy-

steel drills. The heavy-duty high-speed drill, one form of which is shown in Fig. 12, was designed to overcome these disadvantages. It consists of a heavy cast-iron frame *a* of box section bolted to a floor plate *b*. The front of the frame carries the spindle *c*, the back gearing, and the gearing for driving and feeding the spindle. The table *d* is carried on a saddle *e* that is supported by the bracket *f*. This bracket may be moved up or down on the slides *g* on the column, and is supported by a screw jack *h*. The table and the saddle may be moved crosswise by turning the screws *i* and *j*. The machine is driven by an electric motor *k* through back gearing, so that a wide range of speeds may be obtained for the spindle. It is therefore suitable for a variety of drilling operations and also for special work, such as milling and boring.

OTHER TYPES OF DRILLS

24. Multiple-Spindle Drill.—The tendency toward specialization has brought about the use of tools especially designed to save time and prevent error in the duplicating of parts. It has been found that in drilling a large number of holes in one piece, time may be saved by using multiple-spindle drilling machines sometimes called *gang drills*. The term gang drill is also applied to the practice of arranging two or more similar single-spindle drills side by side so that they are operated as a single machine. The multiple-spindle drill shown in Fig. 13 has six spindles in six heads carried on a single cross-rail. The spindles are driven from the same shaft *a* by worms and worm-gears *b*, the shaft *a* connecting with the driving cone *g* through the gears *h* and *i*. The motion for the feed is taken from the shaft *c*, running in the cross-rail, and is transmitted to each spindle by gearing and clutches at *d*, the feed-shaft *c* being driven from the main shaft *a* by a belt on the cone pulleys *e* and *f*, which also furnish the variable feed.

25. The table on the machine shown in Fig. 13 is not movable, and only work of a moderate depth can be drilled in it. This same general type of machine is, however, frequently made

with an adjustable table. The spindle heads can be moved along the cross-rail and set any distance apart, within the range of the machine, and any number of holes from one to

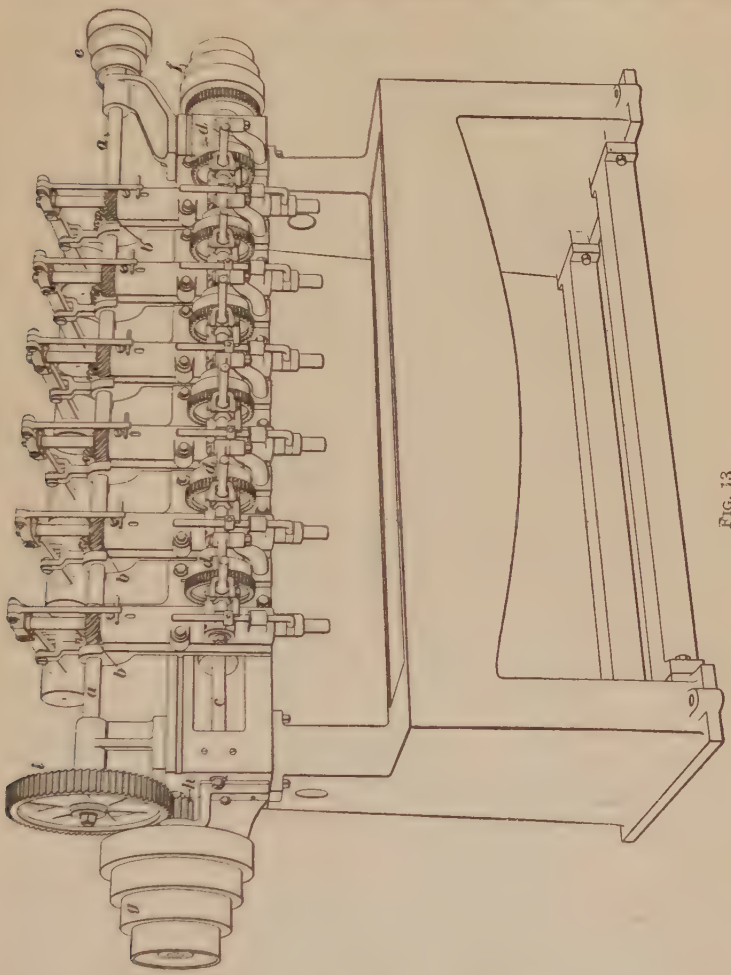

Fig. 13

six may be drilled at the same time. This type of machine is used principally for plate work, structural iron, and other light work requiring a large number of holes in a straight line. Modified forms are used largely for drilling locomotive frames and

bridge chords, and for tapping nuts in large numbers in bolt and nut factories.

26. Universal Adjustable Spindles.—Multiple-spindle drills are frequently made with universal adjustable spindles. The universal joints allow the spindles to be moved in and out as well as along the cross-rail. With this arrangement, holes

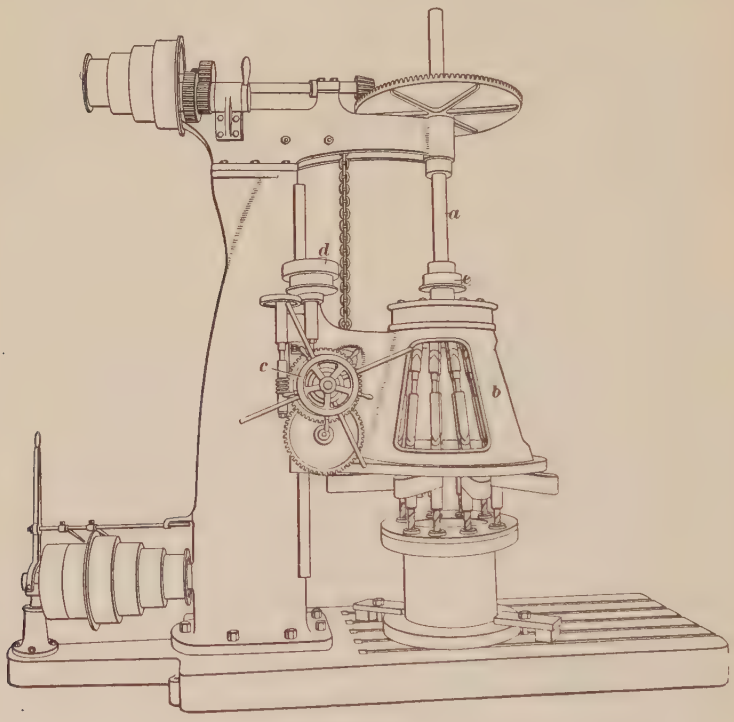

FIG. 14

that are not in line with one another may be drilled at one setting; or, if the holes are to be tapped or reamed and are far enough apart, half of the spindles may be equipped with drills and the other half with taps or reamers, so that when the holes are drilled the piece may be moved to the other set of spindles and finished without taking it off the machine. Jigs should always be used in drilling with universal-joint spindles,

as the short lower bearing is liable to become slightly worn or may not be in perfect adjustment, thus introducing inaccuracies. A well-constructed jig guides the drill perfectly and avoids this danger.

27. Vertical Flange-Drilling Machine.—A very useful multiple-spindle drill is shown in Fig. 14. The spindles, which are arranged about the center of the main driving spindle *a*, are all equipped with universal joints, and each one moves independently of the others. This enables the machine to drill as many holes as there are spindles. The spindles may be arranged in one or more circles or set irregularly, as desired.

28. The machine shown in Fig. 14 is designed for drilling engine cylinders, pipe flanges, valve bodies, etc., but it may be used for almost any work where a regular or irregular grouping of drills is desirable. The illustration shows a piece of flanged pipe clamped on the drill table with jig attached and drills inserted, ready for drilling. The power is transmitted to the spindles by a spur gear on the main spindle *a* and a small pinion on the upper end of each of the drill spindles enclosed in the upper part of the head *b*. The drill spindles are held vertically in both the upper and lower bearings. The feed is obtained by lowering the entire head *b*, which may be done either by means of the pilot wheel *c* or by power by means of a belt running on the cone pulleys *d* and *e*. The smaller machines usually have the drilling head stationary, and the feed is obtained by a vertical movement of the work table.

29. Horizontal Flange-Drilling Machine.—Multiple-spindle drilling machines with two heads set horizontally on a long bed, intended especially for drilling the two ends of engine cylinders, pipes, etc., at the same time, are also in use. The construction of the heads is practically the same as that shown in Fig. 14, the only difference being that they are placed horizontally on the bed. The work is held on a table between the two heads.

DRILLING-MACHINE OPERATIONS

DRILLING, REAMING, AND TAPPING

DRILLING

30. Laying Out.—In many modern machine shops, the laying out of all the work is done in a special department and the work is sent to the machine tools ready for the operation. For the drilling machine, the center of the required hole is first punch-marked. Then a circle having a diameter equal to that of the hole is scribed about it and light prick-punch marks are put at intervals about the circumference, as shown in Fig. 15. The diameter and character of the hole are also marked, usually with chalk. Thus, the note $1\frac{1}{2}''$ *R* indicates that a $1\frac{1}{2}$-inch reamed hole is required.

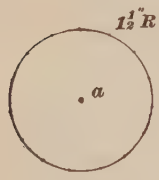

FIG. 15

31. Preparation for Drilling.—When the work reaches the drill, the operator enlarges the center *a*, Fig. 15, with a large center punch, to form a guide for the drill point when beginning the cut. It is practically impossible to start the drill in the center of the hole without the assistance of this deep center mark. The piece is now clamped on the table as conditions require. The drill table is then swung about and adjusted until the center mark stands exactly under the drill point, the drill having been run down to make sure that the point coincides with the center. The table is then clamped to prevent any motion while drilling, the machine is started, and the drill is fed into the work.

32. Starting the Drill.—When the drill has commenced cutting, any unevenness, or varying hardness of the metal, or imperfection in the drill point, tends to carry the point away

from the true center of the hole. As the drill runs down, making a conical hole as shown in Fig. 16, any tendency away from the center may be observed by raising the drill point slightly and blowing or brushing away the chips. If the circle made by the drill is not concentric with the circle of punch marks, the drill has run off from the desired center, and must be brought back. A drawing chisel, shown in Fig. 17, is used for this purpose. This is simply a narrow round-nosed chisel with which the metal is cut away on the side toward which the drill point is to be drawn, as shown in Fig. 18. The cutting should be done quite near the center, as a given amount of metal removed there will draw the drill farther than when the cutting is done near the circumference. The drill is again lowered and the result is observed. If the circle should not be concentric, the chisel is again used and the drill tried; this operation is repeated until the hole coincides exactly with the circle when the drill has entered to its full diameter. If the drill has run badly to one side as when striking a blow hole, it is often necessary to chip from three to five cuts side by side to get the drill back concentric with the circle. The punch marks are cut away equally all around the circumference when the drill has been properly started. The drill is then fed through the piece, or to the desired depth, either by hand or by power, and is backed out by hand.

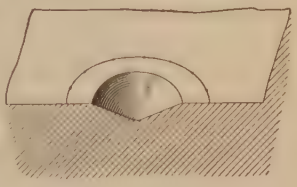

FIG. 16

FIG. 17

FIG. 18

33. Advantages of Power Feed.—All drill presses of the heavier types should be so constructed that either hand or power feed may be used. In light work, enough pressure can be furnished by hand to cause the drill to cut to its full capacity, but in the heavier work a greater pressure is needed. It is contended by some that the

average workman will accomplish more by feeding by hand than by using a power feed, as the tendency seems to be to set the feed at its finest rate, although most drill presses are provided with gearing that will furnish two or more rates. This is the fault of the operator and not of the method. The power feed should be so set that the drill will work up to its limit, which it is impossible with a hand feed when large drills are used.

34. The power feed has several advantages over the hand feed for large sizes of drills. With careless hand feed, the drill may run forwards as the point emerges from the material, causing a rough hole and damage to the drill. The same is true when it enters a blow hole. When drilling flanges, the drill frequently breaks through on one side, and, when the cutting edges stand at a certain angle, the drill runs forwards easily and the next instant takes a heavy cut on one side only. It is evident that this condition will sooner or later result in a damaged drill. With the power feed, all this is avoided, as the drill has a fixed rate of advance. When using the power feed, care must be taken to see that the drill is in proper working condition.

35. Lead Holes.—If the machine has not power enough to drill the full-sized hole in one operation, the hole should be started with a full-sized drill, and drilled about $\frac{1}{4}$ inch deep, central with the laying-out circle. The full-sized drill should then be taken out and replaced by a small drill having a diameter equal to about twice the width of the scraping edge of the large drill. The small drill should be used to drill a lead hole at the center of the hole already started, and should be fed to the desired depth. It should then be replaced by the large drill and the drilling of the hole should be completed. The lead hole removes the metal at the center, so that the scraping edge of the large drill does no cutting. All of the pressure and the cutting then comes on the cutting edges. Sometimes a lead hole is drilled ahead of a drill that is required to cut exactly to its own size.

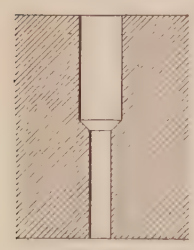

FIG. 19

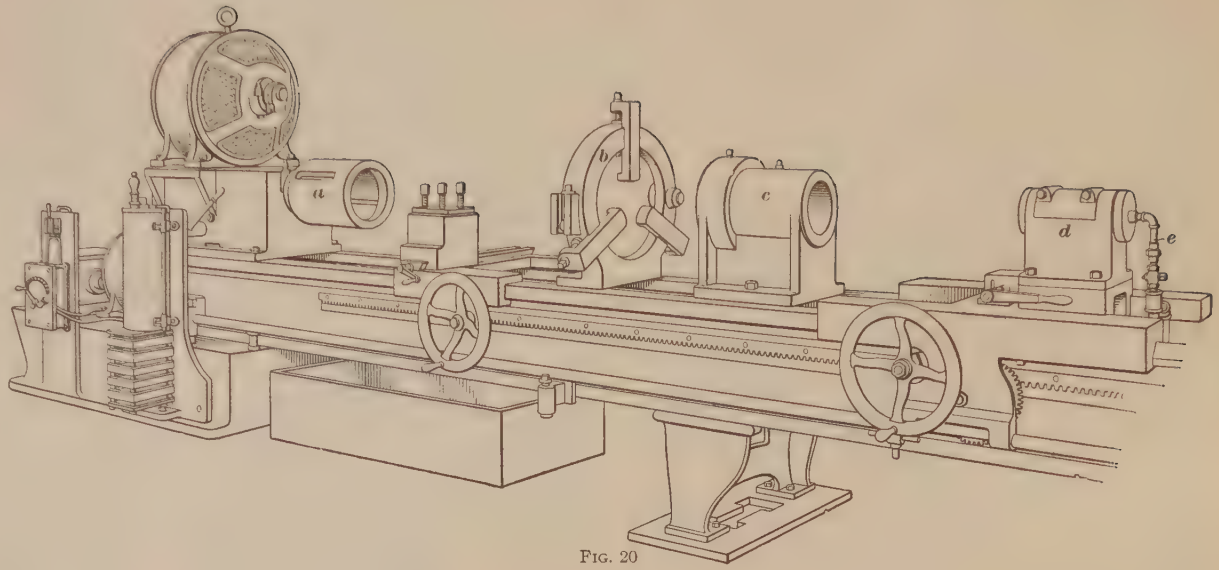

FIG. 20

36. Drilling Deep Holes.—When drilling deep holes through a piece of work, it may be necessary to go deeper than the length of the flutes in the drill of the required size. If the hole is not too deep, the drill may be backed out and the hole cleaned at short intervals. When the hole is very deep, however, time may be saved by running the drill down as far as the chips will discharge, then drilling the remaining depth with a smaller drill, making a hole as shown in Fig. 19. The first drill is then put back into the machine and the entire hole drilled to the full size. The second drill must be small enough so that the chips can work out around it, but must not be so small that the chips made by the larger drill that follows it cannot drop out freely at the bottom. In one instance, where a $1\frac{15}{16}$-inch hole was drilled through 26 inches of solid cast iron, a $1\frac{1}{4}$-inch drill was employed to drill the small hole and gave good results.

37. Drilling holes in solid stock to form rifle and gun barrels, hollow spindles, and similar work is done in special machines of the horizontal type shown in Fig. 20. The work is held and driven by the chuck *a* on the live, or rotating, spindle, and the outer end is supported in the steady rest *b* clamped to the bed. The drill tip, or point, *a*, Fig. 21, is secured to a long holder having an oil groove to match the oil groove *b* cut in the top. The drill has but one cutting edge *c*, and a hole is usually started for it with a short drill. Drilling is performed by feeding the drill into the work through the rest *c*, Fig. 20, by means of the tail-stock *d*. The oil pipe *e* furnishes a constant supply of oil at high pressure, which is delivered under the cutting edge *c*, Fig. 21, and escapes through the flute *d*, carrying the chips or cuttings with it. The drill point is ground in a series of steps, to break up the chips and make them easier to discharge.

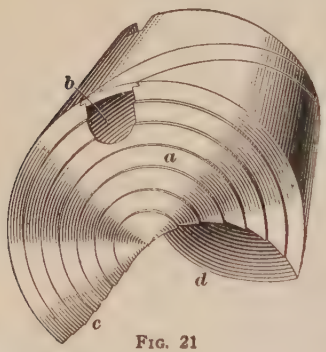

FIG. 21

38. Drilling Holes to be Tapped for Pipe.—Pipe taps, as shown in Fig. 22 (*a*), have a standard taper of $\frac{3}{4}$ inch per foot. The tapping holes for pipe sizes are drilled to the size of the small end of the pipe tap, which is then run into the hole to the required depth to give the correct length of thread. If the pipe tap is required to take out too much stock from the large end of the hole, it is sometimes better to remove the surplus stock with a taper reamer like that shown in (*b*), so that all the tap has to do is to cut the depth of its thread. This makes the tapping process much easier. Straight threads are sometimes required on pipes, and the parts into which the pipes are screwed are threaded with straight pipe taps like that shown in (*c*). The straight pipe tap has the same number of threads per inch as the taper pipe tap of similar size; otherwise, it is simply a plug tap. Table I, at the end of this Section, gives the various dimensions of standard pipe for steam, gas, and water, and shows the sizes of holes to be tapped to fit standard pipe.

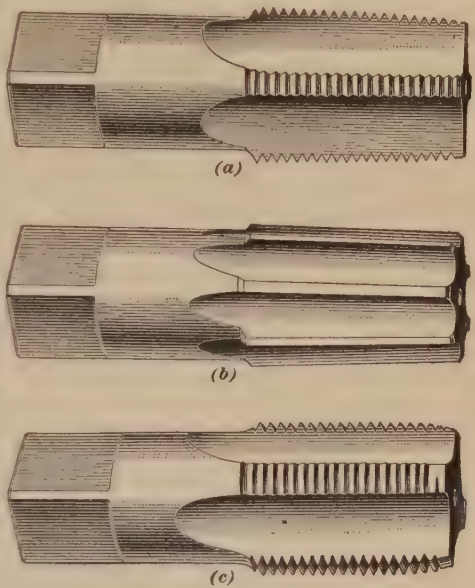

FIG. 22

REAMING

39. Methods of Reaming.—Reaming consists in truing a hole by running a reamer through it. The hole has been drilled or bored, and as it is a matter of economy to do as much work as possible at the same setting, the reaming is done in the

same machine that was used for the drilling or boring. The machine reamer is made with a shank that can be used in a drill press, but is run at a slower speed than the drill and is carefully fed by hand or by power. For very accurate work, the hand reamer is used and is operated by hand, but it may be guided by a center in the drill spindle, as shown in Fig. 23. The reamer *a* is turned with a wrench and is followed up by the center *b*, which also furnishes the necessary pressure to give the feed.

40. Care Necessary in Reaming.—Reaming should be done with the greatest care. Undue forcing of the reamer, any side pressure, or any irregular or jerking motion, tends to injure both the reamer and the hole. A very steady and comparatively slow motion with rapid feed gives the best results. In some cases, the weight of the reamer and the wrench is sufficient to furnish the feed, although some additional pressure is usually necessary. The allowance for hand reaming is usually from 3 to 5 thousandths of an inch.

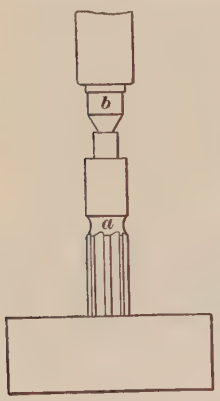

FIG. 23

Structural iron work is often reamed with portable drilling machines. The parts are usually punched as closely as possible to size and then brought into position. The holes do not usually line very well, so a bridge reamer having a taper for a distance of about $1\frac{1}{2}$ inches is placed in a portable drill and fed rapidly through the holes. The tapered part takes out the most of the stock and the parallel portion above sizes the holes. The machine is often suspended from a carrier rail and counterweighted to make the work of handling it easier.

41. Rose Reaming.—Adjoining parts must often be drilled separately, especially when the pieces are large or when it is impossible to drill a continuous hole. A case of the second kind is shown in Fig. 24, in which the two flanges *a* and *b* are to be drilled and joined by bolts *c*. The holes are first laid out, as accurately as possible, on the faces of both parts. Then the

holes d in the part a are drilled and reamed to size with a power drill. The holes e in the part b are drilled from $\frac{1}{16}$ to $\frac{3}{8}$ inch smaller in diameter than the holes d. The flanges a and b are next clamped together accurately and the holes e are reamed to size by a rose reamer that is passed through the holes d. The rose reamer fits the holes d accurately and is run through by a ratchet. It may be followed by a hand reamer if a very accurate hole is required. The rose reamer must be fed much slower than the machine reamer, as it cuts only on the end, and removes a large amount of metal.

42. Machine Reaming.—After a hole has been drilled, it is reamed by replacing the drill with a machine reamer and feeding the latter through the hole at one speed slower than the drill. This one speed slower is obtained by moving the belt

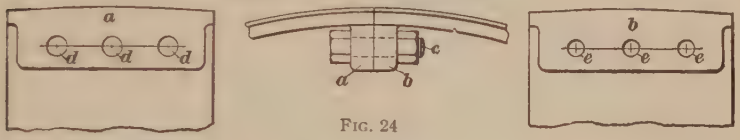

FIG. 24

to the next smaller step on the lower cone pulley of the drill press. The cut of the reamer is light, and the feed should be as fast as possible, to save wear on the reamer.

A tapered hole that is to be reamed by machine is first drilled to the size of the small end of the reamer, which is placed in the spindle or the chuck and is fed into the hole by lever feed, if possible, or else by hand. Plenty of oil is used during cutting, and the reamer is withdrawn and cleaned before the flutes fill with chips. The cleaning operation is repeated as often as may be necessary, until the hole is reamed to the required depth or size. If the chips are allowed to gather in the flutes, the reamer will stick and be broken.

TAPPING

43. Forms of Taps Used.—The forms of taps used in the drilling machine are the same as those used in handwork. The shank is usually made with a square end, or of some other form adapted for chucks or sockets. In ordinary machine

tapping, a taper tap gives the best results. When the thread runs through the material, the tap is run either entirely through or until a thread of the full diameter is formed. When the hole does not run through and the thread must run as near the bottom as possible, the taper tap is used to start the thread, and is followed by a plug tap and a bottoming tap. As in reaming, the speed of the tapping spindle must be slow, and after the tap is started no pressure should be put on it by the feeding device. The tap should be perfectly free to take its own feed.

44. Correct Size of Tapping Hole.—It is very important, when tapping, that the hole is so drilled that a full thread will be formed without removing an excessive amount of metal. This is done by using a tap drill having a diameter equal to the diameter of the tap at the bottom of its thread. When the hole is drilled too small, the tap is very hard to start, and when it is started, the work is so heavy that the tap is often damaged; also, the amount of time and energy required is far greater than is necessary when the hole is of proper size. It is claimed by some, however, that the hole should be drilled larger for cast iron than for wrought iron and steel, and that a thread about three-quarters full in the case of cast iron is stronger than a full thread, owing to the danger of crushing the points of the thread.

A hole that is too large is equally objectionable, as the threads will not be of the full depth, and will, therefore, be imperfect and weak. The tap runs very easily, however, when the hole is large, and for this reason there is a tendency toward making it large, even at some sacrifice in the strength of the thread. This should, however, never be permitted, as the perfect form of the thread should be maintained under all conditions. Table II, at the end of this Section, gives the sizes of tap drills to be used for taps having V threads; Table III gives the sizes of tap drills for machine-screw taps; and Table IV gives the sizes of tap drills for taps having United States standard threads.

COUNTERSINKING, COUNTERBORING, FACING, AND CENTER DRILLING

45. Countersinking.—Countersinks used for accurate work are provided with guides and have but little clearance so that they will not chatter. The most common form of countersink has an included angle of 72°, and is used for flat-head screws. It is simply fed into the work so that the top of the screw head comes flush with the surface of the work. The 60° countersink is used for center holes in lathe work. The 90° countersink is used for valve seats, to remove sharp corners from the ends of holes, and to enlarge holes for riveting. Other angles are used for special work.

46. Facing.—The guide end of the facing bar is well oiled, and the cutter is fed carefully to the cut until the surface is true or until the required depth is reached. If a very heavy facing cut is to be made, it is customary to make a notched roughing cutter remove most of the stock and to use a finishing cutter to complete the work.

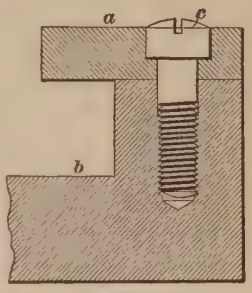

FIG. 25

47. Center Drilling.—The sensitive drill is largely used for center drilling. The piece is first punch-marked to locate the center holes correctly. The lower end is then placed in a cup center or on a conical center and a center drill is used to drill a clearance hole to a depth somewhat greater than that of the required reamed part. The piece is then reversed and the other end is drilled. A center reamer is then substituted for the drill, the speed is reduced, and the holes are reamed to the required size, which should always be in proportion to the size of the work. Most work is drilled and reamed at one operation by the use of a double center drill or a combined drill and reamer.

48. Counterboring.—Suppose that the gib *a*, Fig. 25, is to be secured to the slide *b* by means of $\frac{1}{2}$-inch round-head screws *c*. The holes are first laid out on the gib, which is

clamped securely in position on the slide. A $\frac{13}{32}$-inch tap drill is then used to drill through the gib, and all of the holes are drilled to the required depth in the slide. The gib is then removed from the slide and a head counterbore is substituted for the drill. The guide of the head counterbore is the same size as the tap drill and the holes must be counterbored to the right depth for the screw heads. If flat filister-head screws are used, the counterboring should be so deep that the top of the screw is even with the surface of the work; but the round part of a filister-head screw should project above the work. The body counterbore, which also has a guide the size of the tap drill and a body the size of the screw, is next run through the gib, so that the screw will slide freely through it. The body counterbore is then run into the lower hole for a distance equal to about two threads, and this leaves the hole ready for tapping.

49. Drill-Press Depth Indicators.—Where holes must be drilled or enlarged to certain depths, stops or depth indicators of various designs are used on the column, sleeve, spindle, or sleeve-pinion shaft to indicate when the required depths of cut have been reached. If the head on the column is fed downwards, a clamp with an adjusting screw is used below the head. The clamp is first placed in position and the adjusting screw is set so that the head can be fed down to it, but no farther. All the other holes can be drilled or enlarged only to that depth. Some drills are provided with a clamp and an adjusting screw that can be secured on the spindle sleeve above the arm. This stops downward movement when the adjusting screw reaches the arm. Sometimes the sleeve is graduated or has a steel rule so placed that any depth is indicated by the coincidence of lines.

A disk indicator is sometimes put on the feed-pinion shaft. It consists of a stationary and a rotating disk, and the latter is graduated along the edge with graduations that indicate thirty-seconds of an inch of downward movement of the drill spindle. The rotating disk is set with its zero mark in line with the zero mark on the stationary disk and is clamped to the feed-pinion shaft. Then, as the drill is fed downwards, it will turn and indicate the depth of the hole.

LUBRICANTS

50. When drilling cast iron and brass, no lubrication is necessary; in fact, it retards the work in the case of cast iron. Wrought iron and steel, however, always require lubrication. When tapping, some form of lubricant should be used with all metals, including cast iron. Usually, the lubricant is dropped on the cutting edges with an ordinary oil can; but in multiple-spindle machines, and occasionally in single-spindle machines, a tank, with a tube leading to the tool, is attached to the machine frame, and the flow is controlled by means of a valve in the tube. A small pump carries the lubricant from the table of the machine back to the tank, thus providing a means of using the same lubricant over and over again, and of flooding the cutting edges without undue waste of the lubricating material. Table V, at the end of this Section, gives a list of the lubricants to be used for different operations on different materials, as suggested by the Morse Twist Drill and Machine Company. The mixture mentioned in this table is made of one-third crude petroleum and two-thirds lard oil; and when oil is mentioned, sperm or lard oil is to be used, sperm being preferable. When two lubricants are mentioned, the first is preferred. No lubricant is used in drilling and reaming aluminum, but vaseline or kerosene may be used as a lubricant when tapping this metal.

DRILL GRINDING

51. Hand Grinding of Drills.—When grinding a drill by hand, it is grasped lightly in both hands, with the palms up, the right hand being near the point and the left hand near the shank. The back of the right hand is then rested on the grinder rest and the full length of one cutting edge is brought into contact with the wheel. The shank is then lowered, which raises the cutting edge and grinds the clearance on the drill. This is repeated until the first edge is sharp. The drill is then given a half-turn, without changing the position of the hands, and the other side is ground in the same manner. If the hands are kept in the same relative positions when grinding both lips, the

angles will be the same. These operations are repeated until the drill is sharp. The grinding may be tested by eye by holding the drill with the point up and comparing the angles and lengths of the cutting edges by looking toward the light. Any difference will be noticed readily after a little experience, and may be corrected by repeated grinding.

52. Testing Form of Drill Point.—The similarity of the two cutting edges may be tested, when grinding the drill, in the following manner: The drill is placed in the spindle and fed into

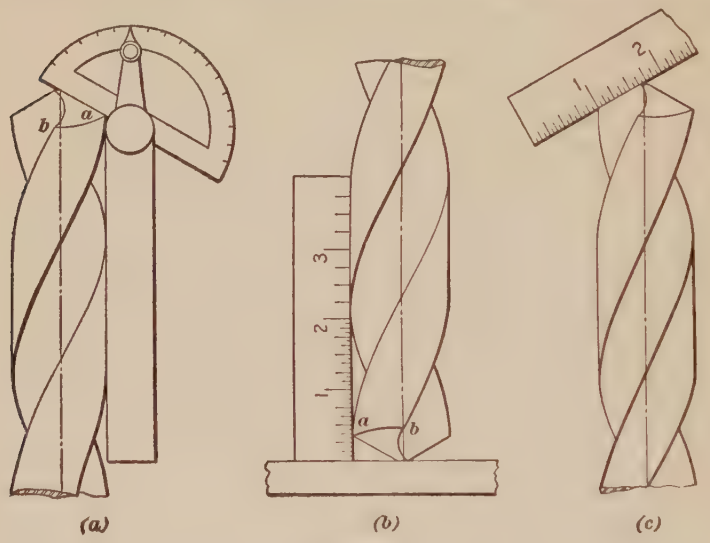

FIG. 26

a piece of scrap cast iron until it cuts the full size and the hole is about $\frac{1}{32}$ inch below the top surface. The machine is then stopped while the feed is still on, so that the chips will not be cut off, and the drill is raised. If the cutting edges are alike, the chip cut by each lip will extend from the center clear to the circumference of the hole, and the drill will cut its own size. If, however, one chip is complete and the other does not reach the circumference, it shows that the latter side of the drill has a shorter cutting edge, and grinding should be continued until the chip is cut evenly to the circumference by each lip.

53. The correctness of shape of the point of a twist drill may also be tested by a gauge, or a protractor, set at the required angle, and applied to the side and edge of the drill, as shown in Fig. 26 (*a*). By turning the drill so as to bring the protractor from the edge *a* to the heel *b*, the clearance angle may be observed, and in this way the two sides may be compared. Another method often used is illustrated in (*b*). The point of the drill is set on a flat surface and a scale is held upright against its side, as shown. The heights of the corners *a* from the point are thus measured. If the two sides are alike, the drill is turned and the heights of the corners *b* are measured, and if these are the same, the clearance angles are equal. The length of the cutting edges may also be tested by applying a steel rule, as shown in (*c*), the portion graduated to thirty-seconds or sixty-fourths, being used. Grinding should be repeated until the two cutting edges measure the same length.

54. Angle and Length of Scraping Edge.—The clearance angle determines the angle of the line *a b*, Fig. 27, representing the scraping edge. This illustration shows about the correct angle. When the angle is too small, as in (*b*), the scraping edge

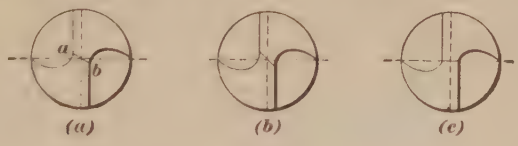

FIG. 27

is too long and greater pressure is required to feed the drill. If the angle of the scraping edge is too great, as in (*c*), there is no clearance at the back of the cutting edges. It is then almost impossible to feed the drill into the work, and if much pressure is applied, the drill is likely to split. The center of the drill is made thicker as it approaches the shank, to strengthen the drill, and so, as the drill is ground shorter, the length of the scraping edge increases. When this increase becomes too great, the drill point should be thinned by grinding out the flutes until the point is reduced to its original thickness. The shape of the flutes should be kept the same as before.

55. Grinding Drills to Cut Larger Holes.—It is frequently necessary to fasten machine parts together by pins cut from wire rods and driven into holes drilled in the parts. It is not customary to fit the pins to the holes but to drill the holes to fit the size of wire available. This is done by selecting a drill usually slightly smaller than the wire and grinding it with one cutting edge longer than the other, so that it will cut enough larger than its size to allow the pins to be driven in with the required degree of tightness. If care is taken in grinding drills, both driving and loose fits may easily be provided for by regrinding the same drill.

DRILLING JIGS AND FIXTURES

DRILLING JIGS

56. Drilling Duplicate Pieces.—Duplicate pieces may be drilled by the use of drilling jigs. A **drilling jig** is a device that may be temporarily attached to the work, to act as a guide for the drill in any desired position. The drill is guided by steel bushings placed over the positions of the required holes. In this way a large amount of time otherwise devoted to laying out may be saved, and when the jig is well made, a degree of accuracy may be attained that is impossible by any other means. The economy of such a device depends on the number of pieces to be drilled and the cost of the jig.

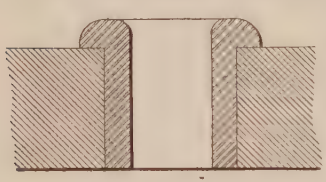

FIG. 28

57. Construction of Drilling Jig.—The body of the jig is usually made of cast iron, but in order to prevent undue wear of the holes, hardened-steel bushings that fit both the jig and the drill snugly are inserted. These bushings are generally made with a shoulder, as shown in Fig. 28, and with the inner corner rounded, to avoid damage to the drill when entering When jigs are used from both sides, the bushings are set as in Fig. 29, the inside corners being rounded on both ends.

When drilling two adjacent parts, as, for instance, the flange and the head of a cylinder, the head may be drilled first, and may then be used as a jig for drilling the cylinder, or as a templet for marking the holes. When a large number of duplicates are to be made, however, it is better to use a jig for both the cylinder and the head.

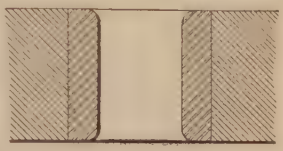

FIG. 29

58. Jig for Drilling Flanges With Regularly Spaced Holes.—In Fig. 30 is illustrated a flange *a* and a jig *b* of the form that is very generally used for this class of work. A lip *c* on the circumference of the jig fits the flange and holds the jig central. When the jig is in the desired position, a clamp is applied to keep it in place while the drilling is being done. When the adjoining flange or head is of the same diameter and the holes are equally spaced on the same circle, it may be drilled with the same jig, by merely turning the jig over, and the holes will be in line when the two parts are put together.

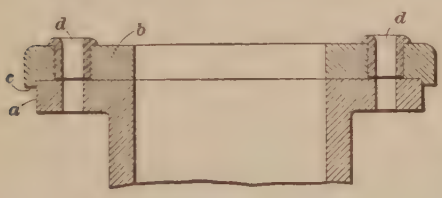

FIG. 30

59. Jig for Drilling Flanges With Irregularly Spaced Holes.—When the holes are not regularly spaced, they cannot be drilled to match by turning the jig over; consequently, it is necessary to make the jig with a lip on each side and with bushings set in, as shown in Fig. 31, so that each side of the jig will fit one of the adjacent flanges. When the flange *a* is drilled with the side *a'* of the jig against it, and the flange *b* with the side *b'* against it, the holes in the two flanges will match however irregularly they may be located.

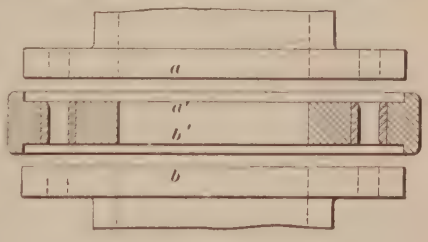

FIG. 31

60. Example of Drilling With Jig.—A jig for drilling the hub and hub plate of a locomotive wheel, in which the holes

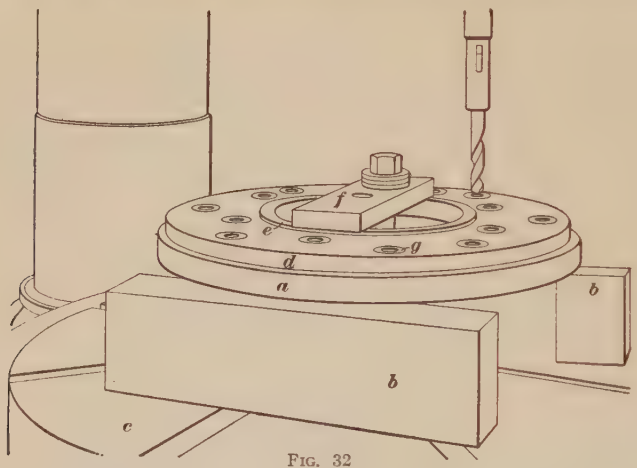

FIG. 32

are not regularly spaced, is shown mounted on a drilling-machine table in Fig. 32. The plate *a* is supported on parallels *b* resting on the table *c*. The jig *d* has a lip *e* on each side, to fit the bores of both the plate and the wheel. The set-in bushings are shown at *g*. A single clamp *f* holds both jig and plate in place.

61. Outside and Inside Jig.—A jig used in drilling two parts, one of which has a projection *a* that must fit into a bored

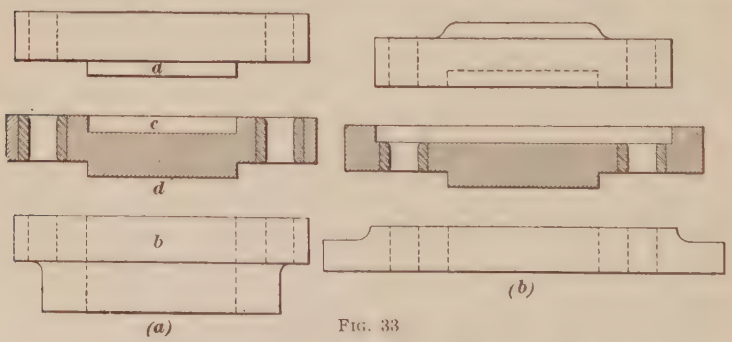

FIG. 33

hole *b* on the other, is shown in Fig. 33 (*a*). The jig is made with a counterbore *c* on one side, which will fit the projection *a*,

and a projection *d* on the other side to fit the bore *b*. This same arrangement may be used when drilling parts of different sizes, as, for instance, a manhole and its cover, as shown in (*b*).

62. Jigs for Irregular Surfaces.—The jigs shown thus far are intended for circular pieces, but the principle involved may be applied to pieces of any form, with either regular or irregular surfaces. Fig. 34 shows a right-hand and left-hand jig used when drilling parts of the saddles of a vertical boring mill. One of the pieces is shown at *a*, and a number of them are piled up at *b*. A right-hand piece *c* and a left-hand piece *d* are bolted on the floor plate of a radial drill,

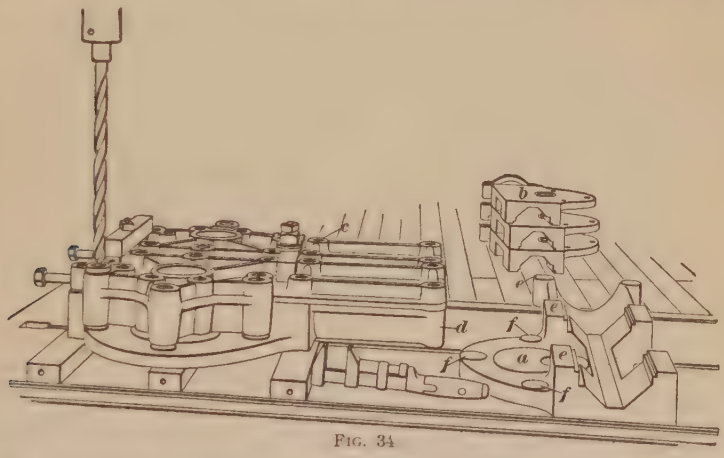

FIG. 34

with the jigs in place ready for drilling. All the holes in the two pieces are drilled without moving either piece. The upper surface of the saddle being uneven, several holes are required on the level *e*, and others on the level *f*. The illustration shows how the jig is formed to fit the uneven surfaces.

63. Drill and Reamer Bushings.—Many holes drilled by the use of jigs require reaming at the same time, in which case different forms of bushings are used. The body of the jig is made of cast iron, as usual, but the bushings, instead of being forced into their seats, are made so that they may be set in with the fingers. Each is a tight sliding fit and is prevented from

turning with the drill by cutting a small key seat in the jig body, as in Fig. 35 (*a*), and putting a pin *a* in the bushing so that it enters the key seat when the bushing is in place. The under side of the flange of the bushing is cut away at one point, as shown at *b*, so that a screw driver can be used to pry out the bushing when a change is to be made.

When a hole is to be drilled and reamed by the use of a jig, the drill bushing is put in the jig and a drill $\frac{1}{64}$ inch small is used to drill the hole. The drill bushing is then replaced by the

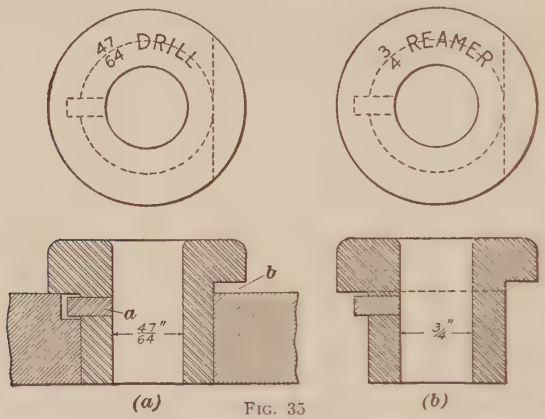

FIG. 35

full-sized reamer bushing, the speed is reduced, and the reamer is run through, which completes the hole.

A pair of bushings suitable for drilling and reaming a $\frac{3}{4}$-inch hole are shown in Fig. 35 (*a*) and (*b*). The drill for the hole is $\frac{47}{64}$ inch in diameter, and the reamer bushing has a $\frac{3}{4}$-inch hole through which the $\frac{3}{4}$-inch reamer passes freely. If holes are completed by drilling, the bushings are tight in their seats, and are made to the full size of the finished hole.

DRILLING AND REAMING LOCOMOTIVE CONNECTING-RODS

64. When drilling and reaming the ends of locomotive connecting-rods and similar work, a machine with two heads supported on a common cross-rail, so that the spindles may be set at any position along the cross-rail, is frequently employed.

Fig. 36 shows the table of such a machine with a connecting-rod *a* fastened upon it. The one spindle is fitted with a drill *b* to form a guide hole for the pin *f* of the annular cutter, and the other spindle is equipped with an annular cutter *c*, with two tools *e* to remove the body of the metal from the hole, the hole having previously been formed for the center pin *f*. The hole formed by the annular cutter is finished with the reamer *d*, which is of the inserted-tooth type. The holes in the reamer are made simply to reduce the weight. The piece is held on the table by two clamps *g* and *h*, the end *i* being laid flat on the surface and the end *j* resting on a parallel *k*, which is equal in thickness to the vertical distance between the two lower faces.

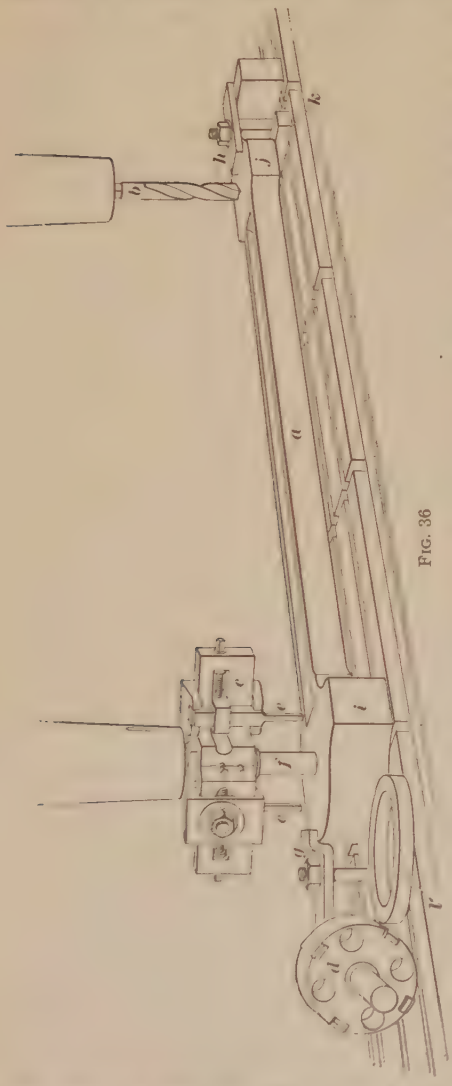

FIG. 36

65. Circular parallels *l*, Fig. 36, of different thicknesses are often used when blocking up the ends of the rod, each size of rod having its own set of parallels. The inside diameter of the parallel is greater than the diameter of the corresponding hole in the rod.

FIXTURES FOR SUPPORTING AND ROTATING WORK

66. V Supports.—A very useful device for drilling rolls is shown in Fig. 37. Two pedestals *a* of suitable height are placed on the base of the drilling machine at a sufficient distance apart to accommodate the work to be drilled. Two V-shaped bearings *b* are placed on the pedestals, and are so lined up that the center of a shaft lying on them will lie in the center lines

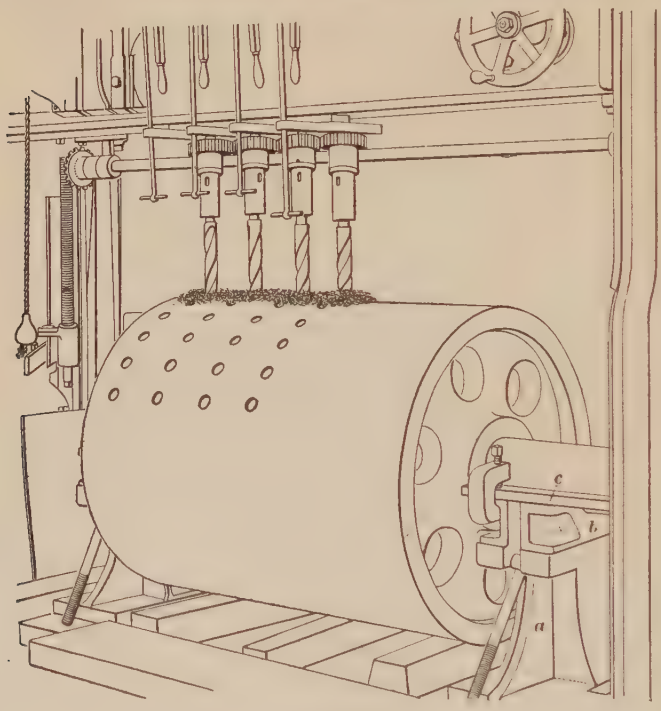

FIG. 37

of the drill spindles. The drills will, therefore, always drill radial holes in a cylinder whose shaft rests on these V's. It is necessary to lay out the holes, place the shaft of the cylinder on the pedestals, and adjust the drill spindles to the right distance apart, and drill in circles about the cylinder, as indicated by the rows of holes shown, the cylinder being turned on the

V's until each successive set of holes comes under the drills. The cylinder is kept from working endwise by the bar *c*, which is set against the hub and clamped to the pedestal. The cylinder shown in this illustration is a crushing roll for anthracite. When the holes are drilled, they must be reamed before the teeth are inserted.

67. Roller Supports.—A roll set up ready for reaming in a radial drill is shown in Fig. 38. It is supported on four

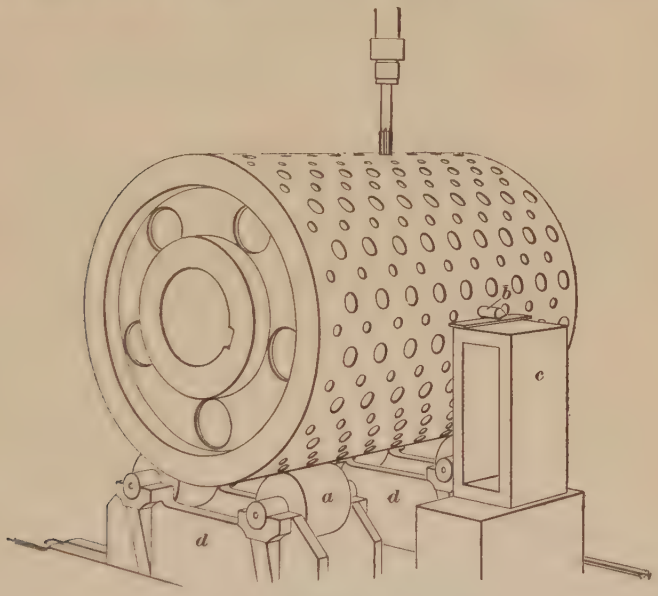

FIG. 38

rollers *a*, held in two frames *d*, one at each end of the roll. The first row of holes is adjusted vertically above the axis of the roll by means of a surface gauge, with which a set of holes on opposite sides of the center are brought an equal distance from the floor. When this adjustment has been made, a pin *b* is inserted in a hole at about the height of the center line, and a block *c* is so fitted that the pin rests on it. This acts as a stop to prevent the roll from turning. When one row of holes is reamed, the pin is moved down one row

and then brought up by turning the roll until it again rests on the block, thus furnishing a very simple means for adjusting each successive row.

68. Heavy Centers.—The device shown in Fig. 39 is very good for holding heavy parts with circular ends, such as pump chambers, under a radial drill. Two uprights *a* and two cones *b* provided with roller bearings, support the work, the cones entering the ends of the work, as shown. A rod *c* passing through the center of the cones and the casting keeps the uprights from spreading. The piece is set in the correct position for drilling one set of flanges, the tie-rod *c* is tightened, and

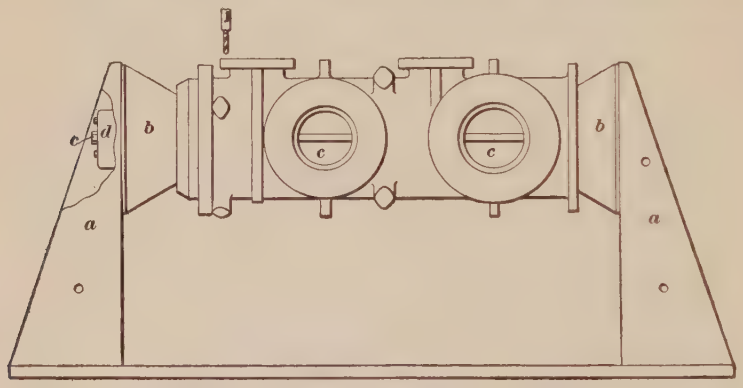

FIG. 39

all the holes in this plane are then drilled. The rod is then loosened slightly and the piece is turned until another face comes into position, when it is again tightened, and the drilling on this face is performed. This operation is repeated until all the holes are drilled. The rollers in the hub *d* reduce the friction of the bearings so that heavy pieces may be turned easily. When any regular series of spaces is required, a special index may be attached at one end, to facilitate the setting.

69. Double Face Plate.—A double face plate to support work that has faced circular flanges with regularly spaced bolt holes is shown in Fig. 40. Two face plates *a* and *b* are supported by a bearing on each side of the bracket *c*, which may be

clamped on the floor plate of a drilling machine. The flanged piece *d*, which is to be drilled and faced at *e*, *f*, and *g*, and at corresponding points opposite *e* and *f*, is attached to the face plate by three arms *h*, bolted to the plate by bolts *i*, and to the flanges by bolts *j*. The face plates are rotated to the right position for drilling, where they are held in place by the latch *k*, which enters notches in the plates. By placing notches at proper points, holes may be drilled at any angle. In the piece shown, the holes are drilled at right angles to each other, and the face plates are held in position by the notches at *k* and *l*. The plates are rotated by bars inserted in a series of holes *m*, *n*, *o*, etc. about the circumference.

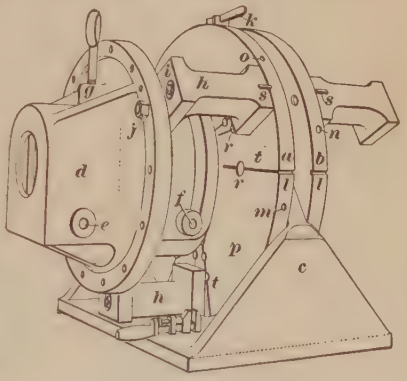

FIG. 40

70. Only one piece is shown attached to the plate *a*, Fig. 40. In doing work, ordinarily, another piece is attached to the plate *b*, thereby balancing the device so as to prevent springing of the bracket *c*, or cramping while turning to a new position. This also permits twice as many holes to be drilled without moving the face plate as when only one piece is attached, and the service of the power crane is required only one-half as often. The face plates may be made to take pieces of various sizes by moving the arms *h* to suitable positions. A series of holes *r* for the bolts *i* are provided, in the face plates shown, to accommodate pieces of different sizes. A large variety of work may be supported in this way by means of suitable arms. A key *s* under each arm, which fits into a corresponding keyway, as shown at *t*, together with the bolt *i*, locates the arm positively. When the piece is out of balance so much as to prevent it from turning, counterweights may be attached to the face plates.

71. Trunnion Supports.—A trunnion fixture for drilling duplex pump cylinders is shown in Fig. 41. The cylinders *a* and *b* are held by means of two plates *c*, which, on one side, have projections entering the ends of the cylinders, and, on the other side, trunnions *d* that rest on V's on the uprights *e* of the frame of the fixture. Bolts *f* hold the plates *c* in place and form guides for the jig *g*, by means of which holes are drilled in the hubs *h* and *i*. When the fixture is in position for drilling, the trunnions are fastened by the clamps *n*.

72. The bushing *j* and the drill *k*, Fig. 41, are shown in place, ready to drill the hole. The hub *i* is supported on the

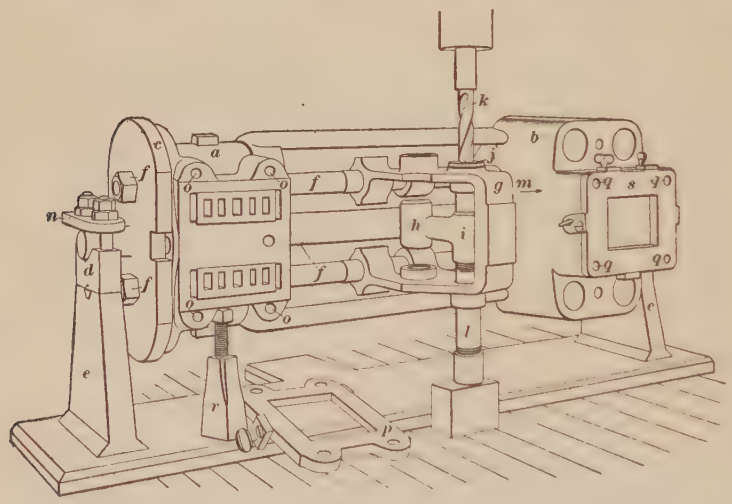

FIG. 41

lower side by a piece of pipe *l*. When both the hubs *h* and *i* are drilled, the jig *g* is moved away from the hubs in the direction of the arrow *m*, and the ends of the hubs are faced with a double-end cutter. The clamp *n* is then loosened and the cylinders are turned on the trunnions *d* to the next position to be drilled. The four holes *o* are drilled with the jig *p*, which is lying on the floor, while the four holes *q* are drilled with the jig *s* attached as shown. These cylinders have holes to be drilled on four sides, and must be set in as many positions.

When the piece is once set up for one position, it is a simple matter to move it to any of the other positions. Screw jacks *r*

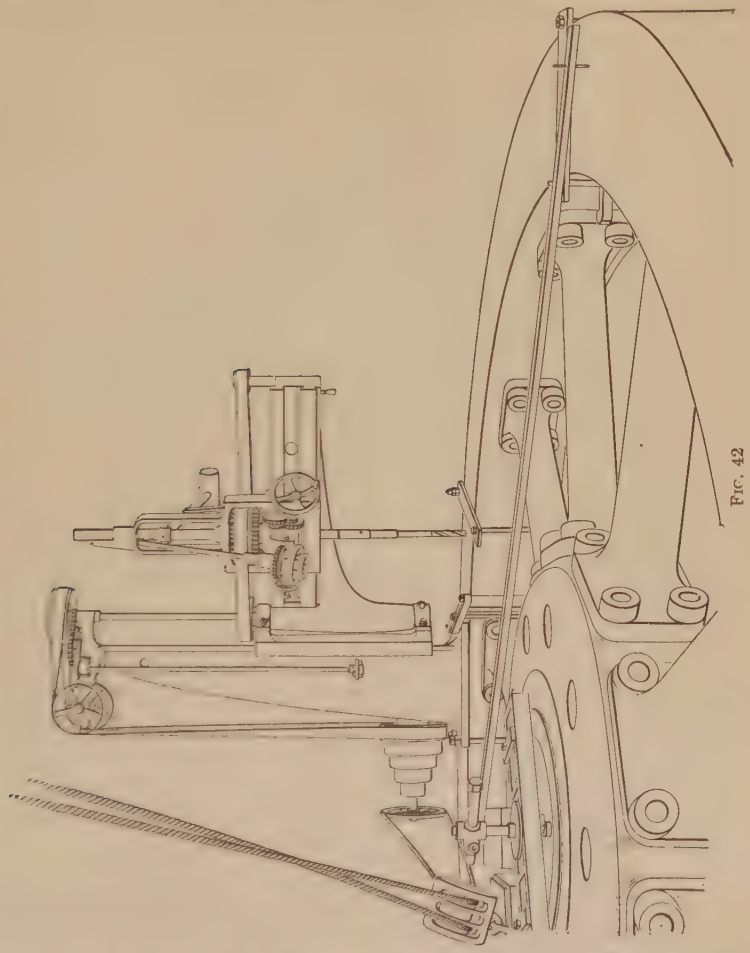

FIG. 42

are used in adjusting and holding the work. The piece may be set in position by means of a square or level.

73. Heavy Drilling Operation.—Parts that are too heavy to be machined in ordinary stationary machine tools are now met with quite commonly in machine shops. This

has led to the use of large cast-iron floors on which the work is placed, and portable machine tools that may be carried to the floor and set up in any position to accommodate the work. Fig. 42 illustrates a case where a 135-ton flywheel was to be drilled at intervals along the rim for the purpose of joining the sections in which it was cast. The separate parts were machined and fitted together; but to make the joints, several 2-inch holes had to be drilled through 26 inches of solid metal. An ordinary radial drill was lifted from its base and set on the rim, as shown. When the holes at one joint were drilled, it was moved to the next joint and the operation was repeated, until all the joints were completed. A rope drive was used in transmitting the power to the drill. The idlers were attached at the center of the wheel, thereby making it possible to move the machine to any point on the rim without changing the length of the rope.

CUTTING SPEEDS AND FEEDS

74. It is not practicable to give rules or tables showing the cutting speeds and feeds to be used in drilling, because there are too many variable conditions to be considered. The rate of cutting will depend on the material being drilled, its degree of hardness, the stiffness of the machine, the quality of the steel of which the drills are made, and the sharpness of the drills. Also, there are some operators who prefer to use a high speed and a slow feed, whereas, others prefer to use a slow speed and a rapid feed. As a consequence, the experience and judgment of the operator must determine the speed and feed required to produce the most economical results.

75. One company manufacturing twist drills recommends an average feed of from .004 to .007 inch per revolution for drills up to and including $\frac{1}{4}$ inch in diameter, and from .007 to .015 inch per revolution for larger sizes. These feeds are for carbon-steel drills and are based on cutting speeds of 30 feet per minute for steel and wrought iron, 35 feet per minute for cast iron, and 60 feet per minute for brass. The speeds of different sizes of drills for steel, iron, and brass are shown in Table VI,

at the end of this Section. If alloy-steel drills are used, the feeds may be kept the same, but the speeds may be doubled, or even trebled. The highest speeds, however, should be reached by gradual stages. It should be clearly understood that the foregoing speeds and feeds are for average conditions only. In some cases they may be exceeded, and in other cases they may have to be reduced. If the corners of the cutting lips of a drill wear away rapidly, the speed should be reduced; and if the drill chips or breaks at the cutting edges, the feed should be reduced.

76. The speeds and feeds that can be used for drills of carbon steel and alloy steel, as suggested by one manufacturer, are given in Tables VII and VIII. They were obtained by a special committee that worked for more than 2 years in testing various sizes of drills at different speeds and feeds to determine the most efficient conditions. These feeds and speeds are much higher than have been suggested heretofore, and should be taken as maximum values. They cannot be used with safety or economy for ordinary drilling machines, but are intended for high-speed ball-bearing machines of stiff and heavy construction. It may be seen that the cutting speed with high-speed drills is double that with carbon-steel drills.

77. Experiments made by the Bickford Drill Company and others show that, with drilling machines of stiff design, heavier feeds and speeds may be used than are usually employed, and that the breaking of drills has been due largely to springing of the drilling machine. It must not be inferred, however, that these experimental feeds can be used in ordinary machines, as extraordinary stiffness in the horizontal arm and vertical column is required to use them successfully. Even with such machines it is not always possible to use them in ordinary practice, and it is probable that slightly lighter feeds may be established for general use with machines of strong design.

The results of these experiments are given in Tables IX to XI, and they will suggest approximately the feeds that can safely be taken in machine tools of great stiffness. Many drills were tested to destruction in ordinary cast iron, and some tests

were made in machinery steel with larger drills, but very few broke. Table IX gives the feeds used in ordinary cast iron without the least injury to the drills. Table X gives the feeds at which the drills broke, and Table XI gives the speeds at which the drills were run.

TABLE I

STANDARD STEAM, GAS, AND WATER PIPE

Sizes of Pipes Inches	Threads per Inch	Actual External Diameter Inches	Actual Internal Diameter Inches	Total Length of Thread Inches	Length of Perfect Thread Inches	Size of Hole for Tap Inches	Diameter of Thread at End of Pipe, in Inches	
							Outside	At Bottom of Thread
$\frac{1}{8}$	27	.405	.270	.41	.19	$\frac{11}{32}$	.393	.334
$\frac{1}{4}$	18	.540	.364	.62	.29	$\frac{7}{16}$	.522	.433
$\frac{3}{8}$	18	.675	.494	.63	.30	$\frac{27}{64}$	.658	.568
$\frac{1}{2}$	14	.840	.623	.83	.39	$\frac{23}{32}$	.815	.701
$\frac{3}{4}$	14	1.050	.824	.84	.40	$\frac{59}{64}$	1.025	.911
1	$11\frac{1}{2}$	1.315	1.048	1.03	.51	$1\frac{5}{32}$	1.283	1.144
$1\frac{1}{4}$	$11\frac{1}{2}$	1.660	1.380	1.06	.54	$1\frac{1}{2}$	1.627	1.488
$1\frac{1}{2}$	$11\frac{1}{2}$	1.900	1.611	1.07	.55	$1\frac{47}{64}$	1.866	1.727
2	$11\frac{1}{2}$	2.375	2.067	1.10	.58	$2\frac{13}{64}$	2.339	2.223
$2\frac{1}{2}$	8	2.875	2.468	1.64	.89	$2\frac{5}{8}$	2.820	2.620
3	8	3.500	3.067	1.70	.95	$3\frac{1}{4}$	3.441	3.241
$3\frac{1}{2}$	8	4.000	3.548	1.75	1.00	$3\frac{3}{4}$	3.938	3.738
4	8	4.500	4.026	1.80	1.05	$4\frac{1}{4}$	4.434	4.234
$4\frac{1}{2}$	8	5.000	4.508	1.85	1.10	$4\frac{3}{4}$	4.931	4.731
5	8	5.563	5.045	1.91	1.16	$5\frac{19}{64}$	5.490	5.290
6	8	6.625	6.065	2.01	1.26	$6\frac{23}{64}$	6.546	6.346
7	8	7.625	7.023	2.11	1.36	$7\frac{11}{32}$	7.540	7.340
8	8	8.625	7.982	2.21	1.46	$8\frac{11}{32}$	8.534	8.334
9	8	9.625	8.937	2.32	1.57	$9\frac{11}{32}$	9.527	9.327
10	8	10.750	10.019	2.43	1.68	$10\frac{29}{64}$	10.645	10.445

NOTE.—The taper of the threaded part is 1 in 16, or $\frac{3}{4}$ inch per foot.

TABLE II

TAP DRILLS FOR TAPS WITH V THREADS

(From Morse Twist Drill and Machine Company)

Diameter of Tap Inch	Threads per Inch	Number of Drill	Diameter of Tap Inch	Threads per Inch	Number or Diameter of Drill	Diameter of Tap Inches	Threads per Inch	Diameter of Drill	Diameter of Tap Inches	Threads per Inch	Diameter of Drill
3/32	48	50	7/32	24	20	19/32	12	31/64	1 7/32	7	1 1/64
3/32	52	50	7/32	28	17	19/32	14	1/2	1 7/32	8	1 9/64
3/32	54	49	7/32	30	16	5/8	10	31/64	1 1/4	7	1 3/64
3/32	56	49	7/32	32	15	5/8	11	1/2	1 9/32	7	1 5/64
3/32	60	48	15/64	24	16	5/8	12	33/64	1 5/16	7	1 7/64
7/64	32	50	15/64	28	12	21/32	10	33/64	1 11/32	7	1 9/64
7/64	36	49	15/64	32	10	21/32	11	17/32	1 3/8	6	1 1/8
7/64	40	47	1/4	18	17	21/32	12	35/64	1 13/32	6	1 5/32
7/64	48	44	1/4	20	14	11/16	11	9/16	1 7/16	6	1 3/16
7/64	56	43	1/4	24	9	11/16	12	37/64	1 15/32	6	1 7/32
1/8	32	44	9/32	16	10	23/32	11	19/32	1 1/2	6	1 17/64
1/8	36	43	9/32	18	13/64	23/32	12	39/64	1 17/32	6	1 19/64
1/8	40	42	9/32	20	3	3/4	10	39/64	1 9/16	6	1 21/64
1/8	42	41	5/16	16	1	3/4	11	5/8	1 19/32	6	1 23/64
1/8	48	39	5/16	18	15/64	3/4	12	41/64	1 5/8	5	1 21/64
9/64	30	41	11/32	16	F	25/32	10	41/64	1 5/8	5 1/2	1 23/64
9/64	32	40	11/32	18	17/64	25/32	11	21/32	1 21/32	5	1 23/64
9/64	36	37	3/8	14	J	25/32	12	43/64	1 21/32	5 1/2	1 25/64
9/64	40	34	3/8	16	L	13/16	10	43/64	1 11/16	5	1 25/64
5/32	30	33	3/8	18	19/64	27/32	10	45/64	1 11/16	5 1/2	1 27/64
5/32	32	32	13/32	14	N	7/8	9	23/32	1 23/32	5	1 27/64
5/32	36	31	13/32	16	P	7/8	10	47/64	1 23/32	5 1/2	1 29/64
5/32	40	30	13/32	18	21/64	29/32	9	3/4	1 3/4	5	1 29/64
11/64	32	30	7/16	14	R	15/16	9	25/32	1 25/32	5	1 31/64
11/64	36	29	7/16	16	S	31/32	9	13/16	1 13/16	5	1 33/64
11/64	40	28	15/32	14	3/8	1	8	53/64	1 27/32	5	1 35/64
3/16	24	29	15/32	16	W	1 1/32	8	55/64	1 7/8	4 1/2	1 35/64
3/16	28	28	1/2	12	25/64	1 1/16	8	57/64	1 7/8	5	1 37/64
3/16	30	27	1/2	13	X	1 3/32	8	59/64	1 29/32	4 1/2	1 37/64
3/16	32	26	1/2	14	13/32	1 1/8	7	59/64	1 29/32	5	1 39/64
3/16	36	24	17/32	12	27/64	1 1/8	8	61/64	1 15/16	4 1/2	1 39/64
13/64	24	26	17/32	13	27/64	1 5/32	7	61/64	1 15/16	5	1 41/64
13/64	28	22	17/32	14	7/16	1 5/32	8	63/64	1 31/32	4 1/2	1 41/64
13/64	32	20	9/16	12	29/64	1 3/16	7	63/64	1 31/32	5	1 43/64
13/64	36	18	9/16	14	15/32	1 3/16	8	1 1/64	2	4 1/2	1 43/64

TABLE III

TAP DRILLS FOR MACHINE-SCREW TAPS

(From Morse Twist Drill and Machine Company)

Size of Tap	Number of Drill	Size of Tap	Number of Drill	Size of Tap	Number or Letter of Drill
2×48	50	9×30	27	17×16	6
2×56	49	9×32	25	17×18	2
2×64	48	10×24	25	17×20	2
3×40	47	10×30	22	18×16	2
3×48	45	10×32	21	18×18	1
3×56	44	11×24	21	18×20	B
4×32	43	11×28	17	19×16	A
4×36	42	11×30	17	19×18	C
4×40	41	12×20	19	19×20	D
5×30	40	12×22	17	20×16	D
5×32	40	12×24	17	20×18	F
5×36	38	12×28	15	20×20	H
5×40	37	13×20	15	22×16	J
6×30	35	13×22	15	22×18	L
6×32	35	13×24	13	24×14	M
6×36	33	14×20	13	24×16	N
6×40	32	14×22	11	24×18	O
7×28	32	14×24	9	26×14	O
7×30	31	15×18	10	26×16	P
7×32	30	15×20	8	28×14	R
8×24	30	15×22	6	28×16	S
8×30	30	15×24	5	30×14	U
8×32	29	16×16	7	30×16	V
9×24	29	16×18	6		
9×28	28	16×20	5		

NOTE.—For steel work use a drill one or two sizes larger than listed.

TABLE IV

TAP DRILLS FOR TAPS WITH UNITED STATES STANDARD THREADS

(From Morse Twist Drill and Machine Company)

Diameter of Tap Inch	Threads per Inch	Diameter or Letter of Drill	Diameter of Tap Inches	Threads per Inch	Diameter of Drill	Diameter of Tap Inches	Threads per Inch	Diameter of Drill	Diameter of Tap Inches	Threads per Inch	Diameter of Drill
1/4	20	3/16 in.	11/16	11	37/64	1 1/4	7	1 5/64	2 1/8	4 1/2	1 27/32
5/16	18	C	3/4	10	5/8	1 3/8	6	1 11/64	2 1/4	4 1/2	1 31/32
3/8	16	N	13/16	10	11/16	1 1/2	6	1 19/64	2 3/8	4	2 1/16
7/16	14	S	7/8	9	47/64	1 5/8	5 1/2	1 25/64	2 1/2	4	2 5/16
1/2	13	13/32 in.	15/16	9	51/64	1 3/4	5	1 1/2			
9/16	12	29/64 in.	1	8	27/32	1 7/8	5	1 5/8			
5/8	11	33/64 in.	1 1/8	7	61/64	2	4 1/2	1 23/32			

TABLE V

LUBRICANTS FOR DRILLING, REAMING, AND TAPPING

(From Morse Twist Drill and Machine Company)

Material	Drilling	Reaming	Tapping
Tool Steel	Oil	Lard oil	Oil
Soft steel	Oil or soda water	Lard oil	Oil
Wrought iron	Oil or soda water	Lard oil	Oil
Cast iron	Dry	Dry	Oil
Brass	Dry	Dry	Oil
Copper	Oil	Mixture	Oil
Babbitt	Dry	Dry or kerosene	Oil
Glass	Turpentine		

TABLE VI

SPEEDS AND FEEDS FOR CARBON-STEEL DRILLS

(From Cleveland Twist Drill Company)

Diameter of Drill Inch	Materials			Diameter of Drill Inches	Materials		
	Soft Steel	Iron	Brass		Soft Steel	Iron	Brass
	Revolutions per Minute				Revolutions per Minute		
1/16	1,824	2,128	3,648	1 1/16	108	125	215
1/8	912	1,064	1,824	1 1/8	102	118	203
3/16	608	710	1,216	1 3/16	96	112	192
1/4	456	532	912	1 1/4	91	106	182
5/16	365	425	730	1 5/16	87	101	174
3/8	304	355	608	1 3/8	83	97	165
7/16	260	304	520	1 7/16	80	93	159
1/2	228	266	456	1 1/2	76	89	152
9/16	203	236	405	1 9/16	73	85	145
5/8	182	213	365	1 5/8	70	82	140
11/16	166	194	332	1 11/16	68	79	135
3/4	152	177	304	1 3/4	65	76	130
13/16	140	164	280	1 13/16	63	73	125
7/8	130	152	260	1 7/8	60	71	122
15/16	122	142	243	1 15/16	59	69	118
1	114	133	228	2	57	67	114

TABLE VII

FEEDS AND SPEEDS FOR CARBON-STEEL DRILLS

(Copyrighted by Henry & Wright Manufacturing Company and used by permission)

Diameter of Drill Inches	Feed per Revolution Inch	Materials to be Drilled							
		Brass or Bronze	Annealed Cast Iron	Hard Cast Iron	Mild Steel	Drop Forgings	Malleable Iron	Tool Steel	Steel Castings
		Cutting Speed, in Feet per Minute							
		150	85	40	60	30	45	30	20
		Revolutions per Minute of Drill							
$\frac{1}{16}$	.003		5,185	2,440	3,660	1,830	2,745	1,830	1,220
$\frac{1}{8}$	.004	4,575	2,593	1,220	1,830	915	1,375	915	610
$\frac{3}{16}$	.005	3,050	1,728	813	1,220	610	915	610	407
$\frac{1}{4}$	.006	2,287	1,296	610	915	458	636	458	305
$\frac{5}{16}$	.007	1,830	1,037	488	732	366	569	366	245
$\frac{3}{8}$	.008	1,525	864	407	610	305	458	305	203
$\frac{7}{16}$	.009	1,307	741	349	523	261	392	261	174
$\frac{1}{2}$	.010	1,143	648	305	458	229	343	229	153
$\frac{5}{8}$	.011	915	519	244	366	183	275	183	122
$\frac{3}{4}$	.012	762	432	204	305	153	212	153	102
$\frac{7}{8}$	.013	654	371	175	262	131	196	131	87
1	.014	571	323	153	229	115	172	115	77
$1\frac{1}{4}$	.016	458	260	122	183	92	138	92	61
$1\frac{1}{2}$	.016	381	216	102	153	77	106	77	51
$1\frac{3}{4}$	.016	327	186	88	131	66	98	66	44
2	.016	286	162	87	115	58	86	58	39

TABLE VIII

FEEDS AND SPEEDS FOR HIGH-SPEED STEEL DRILLS

(Copyrighted by Henry & Wright Manufacturing Company and used by permission)

Diameter of Drill Inches	Feed per Revolution Inch	Materials to be Drilled							
		Brass or Bronze	Annealed Cast Iron	Hard Cast Iron	Mild Steel	Drop Forgings	Malleable Iron	Tool Steel	Steel Castings
		Cutting Speed, in Feet per Minute							
		300	170	80	120	60	90	60	40
		Revolutions per Minute of Drill							
1/16	.003			4,880		3,660		3,660	2,440
1/8	.004		5,185	2,440	3,660	1,830	2,745	1,830	1,220
3/16	.005		3,456	1,626	2,440	1,210	1,830	1,220	807
1/4	.006	4,575	2,593	1,220	1,830	915	1,375	915	610
5/16	.007	3,660	2,074	976	1,464	732	1,138	732	490
3/8	.008	3,050	1,728	813	1,220	610	915	610	407
7/16	.009	2,614	1,482	698	1,046	522	784	522	348
1/2	.010	2,287	1,296	610	915	458	636	458	305
5/8	.011	1,830	1,037	488	732	366	569	366	245
3/4	.012	1,525	864	407	610	305	458	305	203
7/8	.013	1,307	741	349	523	261	392	261	174
1	.014	1,143	648	305	458	229	349	229	153
1 1/4	.016	915	519	244	366	183	275	183	122
1 1/2	.016	762	432	204	305	153	212	153	102
1 3/4	.016	654	371	175	262	131	196	131	87
2	.016	571	323	153	229	115	172	115	77

TABLE IX

FEEDS USED IN ORDINARY CAST IRON WITHOUT INJURY

Diameter of Drill Inches	Feed per Revolution Inch
$\frac{1}{4}$ to $\frac{1}{2}$	.025
$\frac{1}{2}$ to 1	.035
1 to $1\frac{1}{2}$	.047

TABLE X

FEEDS AT WHICH DRILLS BROKE IN ORDINARY CAST IRON

Diameter of Drill Inch	Feed per Revolution at Which Drill Broke Inch	Diameter of Drill Inch	Feed per Revolution at Which Drill Broke Inch
$\frac{1}{16}$	.007	$\frac{3}{16}$	.035
$\frac{3}{32}$	.010	$\frac{1}{4}$	.047
$\frac{1}{8}$	.014	$\frac{5}{16}$	.064
$\frac{5}{32}$	.020		

TABLE XI

SPEEDS AT WHICH DRILLS WERE RUN

Diameter of Drill Inches	Revolutions per Minute	Cutting Speed Feet per Minute	Diameter of Drill Inches	Revolutions per Minute	Cutting Speed Feet per Minute
$\frac{1}{2}$	267	35	$1\frac{3}{4}$	61	28
$\frac{5}{8}$	222	36	2	51	26
$\frac{3}{4}$	184	36	$2\frac{1}{4}$	42	25
$\frac{7}{8}$	153	35	$2\frac{1}{2}$	35	23
1	128	33	$2\frac{3}{4}$	29	21
$1\frac{1}{8}$	106	31	3	24	19
$1\frac{1}{4}$	88	29	$3\frac{1}{4}$	20	17
$1\frac{1}{2}$	73	28	$3\frac{1}{2}$	17	15

GENERAL APPLIANCES AND PROCESSES
(PART 1)

GENERAL SHOP APPLIANCES

OILS AND LUBRICATION

KINDS AND USES OF LUBRICANTS

1. When two bodies move against each other, friction is produced; and when metal is removed by cutting, heat is generated. A **lubricant** is a substance, such as oil, grease, or graphite, used to diminish the friction between the working parts of machinery or to carry away heat. Oils are also used for cleaning purposes.

2. The lubricants used in shops are generally the *mineral* and *animal oils*. **Mineral oils** are obtained by refining crude petroleum, taken from the earth. In the refining process many different grades of oil are produced varying from the light, volatile gasoline to the heavy cylinder oil. Intermediate forms of mineral oils are kerosene, naphtha, benzine, and machine oil. **Animal oils** are obtained from animals. Lard and sperm oils are the animal oils used in shop practice. Turpentine and mineral substitutes for lard and sperm oil are also used for lubrication.

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OILS FOR CLEANING

3. **Benzine, naphtha,** and **turpentine** are used considerably in shops for cleaning purposes; these oils evaporate very rapidly and form highly inflammable vapors. If these vapors are mixed with air in certain proportions, they form explosive mixtures that need but a spark to ignite them. For this reason, great care should be taken not to have a naked light or any fire close to any of these volatile oils.

4. **Gasoline, kerosene,** or **coal oil,** and **sperm** oil are among the most fluid commercial oils. They will flow into smaller spaces than heavier oils, but have the disadvantage that they lack body; that is, they evaporate quickly, and consequently are of little value as lubricants. They are of great value, however, when used to clean rubbing surfaces, as they will dissolve or thin down almost any heavier oil, and can be employed for cleaning bearings, etc., where it is suspected that the oil channels have become clogged by the gumming of the regular oil. A copious and constant supply of kerosene or mineral sperm oil may be applied to the bearing until the oil comes out clear; it must then be followed immediately by a plentiful application of the heavier oil generally used for lubrication, in order to prevent any cutting of the rubbing surfaces owing to their becoming dry through the rapid evaporation of the light oil. These light oils are also employed for lapping operations.

5. The lighter oils can often be used advantageously for thinning down the heavier oils in order to make a grade suitable for some special purpose. Most of the lighter oils are quite inflammable, and consequently due care must be taken to prevent their ignition.

REDUCING FRICTION BY LUBRICATION

6. **Selection of Lubricant.**—A lubricant reduces friction by interposing itself in the form of a thin film, which may be considered as being composed of a large number of minute globules, between the rubbing surfaces of the moving bodies.

These globules act as rollers or balls, and convert the sliding friction into a rolling friction to an extent depending on their deformation under the load they carry. The deformation of the globules of the lubricant depends on its consistency, and is greater for a thin lubricant than for a heavy thick one. A thick oil should therefore be selected for heavy pressures, while for light pressures a thin oil may be used. The contact between the rubbing surfaces must also be duly considered in connection with the selection of a lubricant, and one used that is fluid enough to flow in between the surfaces. Thus, in machine tools and fine machinery, the rubbing surfaces are usually fitted very closely to each other, and hence fluid mineral oil having sufficient body to last a reasonable length of time must generally be used.

7. Machine Oil.—Machine oil is a mineral oil having considerable body; it is well adapted to general shop use, and should be thin enough to run freely through the oil holes and oil channels of bearings. Animal oils are generally objectionable as machine oils, for decomposition by age is liable to develop fatty acids that attack most metals; they are also very liable to gum; that is, some of their constituent parts will collect into a sticky mass and close the oil channels of bearings. Machine oil, and all oil intended for lubrication, should be entirely free from grit. By examining a drop of the oil with a strong magnifying glass, the presence of grit may be readily discovered.

8. Cylinder Oil.—A special grade of heavy oil known to the trade as *cylinder oil*, is used for the lubrication of parts subjected to fairly high temperatures, as the valves and pistons of steam engines. It has the property of standing considerable heating without volatilizing or being decomposed. Owing to its heavy body, it is used sometimes for bearings subjected to heavy pressures.

9. Greases.—Oils in the solid state are known as *greases*. They may be either of the mineral or animal variety, although usually of the latter, and are soft and plastic. For very heavy work and relatively low rubbing speeds, one of the many forms

of manufactured grease is frequently used. The bearings must then be fitted loosely enough to admit the grease. The great body, which is the characteristic feature of a grease, prevents its being crushed or squeezed out by the weight of the moving parts.

10. Grease of the best quality may be used to advantage in putting ball-bearing work together, when difficulty is experienced in keeping the balls in place while assembling the bearing. The ball races, or seats, are filled with the grease and the balls are then pressed into it. The grease will hold the balls in place while the parts are being put together, and will serve to lubricate them for a long time afterwards. This is a very convenient aid in assembling the ball bearings of the pneumatic drilling machines now so commonly used in large shops.

11. Bearings of shaftings and machines that are subject to great wear and are not always under the eye of the attendant, or easily within reach, and hence are liable to run dry with the ordinary methods of oiling, are thus provided for: Grease cups are screwed, or grease pockets are cast, on places where bearings are liable to heat; these are filled with a grease that will not melt until the bearing becomes warm, when it runs down through the oil holes to the surfaces needing lubrication.

12. Graphite.—*Graphite*, *black lead*, or *plumbago* is a solid mineral substance that forms an excellent lubricant. When ground fine it may be used either dry or mixed with some fluid lubricant or grease to a consistency considered suitable for the work. Graphite is one of the most refractory substances known, and is therefore an invaluable lubricant for bearings subjected to high temperatures. Its lubricating qualities at all temperatures are so good that it forms a very valuable addition to almost any oil.

13. Lubricating Hot Bearings.—A bearing will get hot by reason of friction due to an insufficient or interrupted supply of the lubricant, or because of the journal fitting so close that the lubricant cannot pass between the rubbing surfaces. When a bearing gets hot, it should at once be supplied with a liberal

quantity of oil, and the application repeated frequently until the bearing commences to cool. If the bearing becomes so hot that it smokes before the hot bearing is discovered, and it is not advisable to stop the machine, water may be poured down the oil hole on the bearing, or a hose played on the bearing until it is cool. When a hot bearing is discovered, the cap may be slacked back somewhat so as to allow a free circulation of the lubricant. As soon as the bearing is cool, a copious and constant supply of oil, which may have some graphite mixed with it, should be provided and the results noted. If the bearing refuses to keep cool after this, the rubbing surfaces are probably in such a bad condition as to need refitting.

If the hot bearing is rigid—that is, not self-adjusting to the shaft—observe whether one end is hotter than the other; also test the shaft for alinement, as the heating of the bearing may not be caused by a defect in the hot box, but by the bearing next to it getting out of line, thus bringing all the load on one end of the bearing that is heating.

14. Oil Holes and Oil Channels.—Various means are provided to make sure that the lubricant reaches the place or surface it is intended to cover. In the first place, oil holes are drilled through the metal from the high side so that the oil will reach its proper place by gravity. The size of the oil holes should vary with the kind of lubricant that is to be used, drilling small holes in small work and for a fluid lubricant, and larger ones as the heaviness of the oil and the length of the hole increase. Bearings that are not easily reached must have tubing or pipe run to them as directly as possible; this oil piping should be supplied with fittings that allow it to be easily taken down and cleaned.

15. Oil channels should be cut so as to distribute the oil over the whole length of the bearing; also, such other channels should be provided as may be needed to insure an even distribution of the lubricant. To insure thorough lubrication, the oil channels must have a liberal width and must be so deep as not to become filled too rapidly with the impurities some lubricants contain. Furthermore, the direction in which the

oil channels run from the point of supply (the bottom of the oil hole) should be the same as the direction of rotation of the journal, in order that the latter may tend to draw in the oil rather than to repel it. A lubricant will not flow up hill any more than any other liquid; hence, it should always be applied at the highest point permitted by circumstances.

LUBRICATION OF CUTTING TOOLS

16. The cutting speed of a tool may often be considerably increased by the application of some kind of lubricant, such as oil or water. When oil is used, it reduces the friction between the shaving and the face of the tool, and thus reduces the heating. If a sufficient quantity is used, it also carries off much of the heat generated by the cutting operation and keeps the tool from getting as hot as it otherwise would; consequently, the cutting speed may be increased without overheating the cutting edge.

Cast iron is usually worked dry. The dirt caused by mixing fine cast-iron turnings with oil or water on the machine more than overbalances the possible increase in cutting speed. Furthermore, it is difficult to take a light cut on cast iron when it is oily. The oil soaks into the surface of the iron for a short distance and seems to form a skin that is not easily broken. If the cut is deeper than a finishing cut, the oil on the surface will not impede the cutting. Brass, copper, and Babbitt metal are generally cut without a lubricant, although work composed of these metals is sometimes flooded with lard oil in automatic screw-machine work, thereby reducing friction and prolonging the life of the tools.

17. Lubricants Used in Cutting Steel and Wrought Iron.—The best lubricants to use when cutting steel or wrought iron are the best grades of lard oil and sperm oil. Lard oil is a much heavier oil than sperm oil and is generally used for this class of work. Sperm oil is employed chiefly for very light work. It is a good oil to mix with the abrasive when lapping. One of these oils should be used for all thread-cutting or reaming

operations. For turning shafts, soda water is used, or in some cases a mixture of soft soap and water. Soda water is an excellent medium for absorbing heat; the soda also keeps the water from rusting the machines or the work. Soft soap dissolved in water is used in some shops instead of soda water and possesses some lubricating quality. When a finishing cut is taken on soft iron or steel with a keen tool, and a supply of water is kept on the tool, a very bright smooth surface is produced. Such a cut is called a *water cut;* some kinds of work are thus finished with sufficient smoothness to make polishing unnecessary.

18. Cheap Lubricant for Tools.—For some classes of work, a cheap and satisfactory lubricant may be made by combining oil with other ingredients. There are many such mixtures in use in which an oil is first thinned down by mixing it with a cheap soda water, and then adding some ingredient that will give body to the lubricant—that is, thicken it enough to make it somewhat adhesive. A good lubricant may be made by mixing together $\frac{1}{4}$ pound of sal soda, $\frac{1}{2}$ pint of lard oil, $\frac{1}{2}$ pint of soft soap, and enough water to make 10 quarts, boiling $\frac{1}{2}$ hour, and stirring well. When cool, it is ready for use. This mixture can easily be handled by a pump, and is quite satisfactory for general use.

19. Lubricants for Cutting Babbitt Metal.—In most cases, Babbitt metal may be worked dry; but when bushings of this material are being bored in the lathe or when boxes are machined in position, a lubricant is often found necessary. This is especially true of bushings that are being bored in the lathe, since the chip has a tendency to wind around the boring tool and form a compact ball. Boxes that have been bored and are to be reamed will sometimes be scored or roughened in the reaming if the work is done dry. Lard oil is sometimes used in working Babbitt metal, but a copious supply of kerosene oil will give far better results than any other lubricant.

20. Lubricants for Drilling Rawhide.—If a twist drill must be used to drill rawhide, drilling in general will be found a trying and tedious job, owing to a tendency to clog the flutes

of the drill when the drilling is done dry. If a cake of ordinary laundry soap is held against the drill every little while, however, no trouble will be experienced. The drill should be run quite fast for drilling rawhide.

21. Lubricants for Fitting.—Fitters who are working on cast-iron work must sometimes use a lubricant, other than the marking material, when they are rubbing two parts together in order to obtain bearing marks. Oil will prevent the seizing and cutting of the surfaces; but it will leave no bearing marks, and, besides, it will interfere with the scraping. Turpentine may be used freely on such work, however, and will prove beneficial.

22. Pipe System of Lubrication.—When a large number of machine tools are used on work where constant lubrication is necessary, the tank containing the lubricant is often placed in some warm out-of-the-way locality, as in the boiler room. A system of piping having branch pipes leading to the different machines may then be laid through the shops. A force pump should have its suction pipe connected to the tank and its discharge pipe connected with the pipe system. All the drippings may be automatically returned to another tank near the first through a separate pipe system so arranged that they will flow back by gravity. By grouping together all the machines requiring lubrication, the piping system can be made relatively inexpensive. The placing of the tank in the boiler room is especially convenient when mixtures require boiling, since a steam coil can then be placed in the tank at small expense.

Sometimes, the supply tank is located at such a height that the lubricant will flow to the machines by gravity, and the pump is used to raise it from the lower to the upper tank. The oil should always pass through a strainer or a filter before being used again.

23. Oil Separator.—Shops in which a great deal of screw-machine work, milling, and tapping of wrought iron or steel is done, use correspondingly large quantities of oil to lubricate the cutting tools. This oil becomes mixed with the cuttings or chips from the work, and while most of the oil can be drained

off, a large amount adheres firmly to the chips and is usually thrown away. Much of it may be saved by collecting the oily chips, and running them through a separator. This separator consists of a circular tank that is open at the top and is provided with a cock in the bottom, to allow the extracted oil to be drained off. A vertical spindle passing up through the center of the tank carries a strong conical steel pan provided with an equally strong cover that is held on, when in use, by a locknut. The edge of the pan has small openings for the escape of the oil. A pulley is provided on the lower end of the spindle to drive the extracting pan, and is belted to an overhead countershaft.

The pan is filled with the oily chips, the cover securely fastened, and the machine started slowly and allowed to come up to its full speed, which should be about 7,000 feet per minute at the periphery of the pan. The oil is thrown from the chips by the centrifugal force and finds its way out through the small openings in the top edge of the pan. As the oil flies from the pan it is caught by the wall of the tank and flows down to the oil well.

24. Oil Filter.—Oil that has been used a number of times is liable to be filled with very fine chips that separators will fail to remove. Such oil may be filtered through an oil filter; in its absence blotting paper will be a fair substitute. Some of the heavier particles of metal in the oil can be gotten rid of by letting the oil stand in a quiet place for some time, when the heavy foreign matter will settle to the bottom of the vessel. The clear oil may then be poured off into another vessel. This settling process will not clean the oil as effectually as an oil filter. Oil cleaned by the settling process should never be used for lubricating bearings, but only for the cutting tools. An oil filter or settling tank will not work well if kept in a cold place.

MISCELLANEOUS DEVICES

25. Boxes, Pans, and Trays.—All shops and manufacturing establishments doing small work have more or less trouble in moving small parts from place to place. This is generally done by using such boxes, kegs, and barrels as happen to be at hand. These soon become dirty or are broken, and must then be replaced.

An excellent substitute for these makeshift devices is found in the metallic articles illustrated in Fig. 1. The one shown in (*a*) is a steel box that can be used for many shop purposes. The pressed-steel pan illustrated in (*b*) may be employed instead of the box, and has the advantage that it will hold water or oil. These pans, when not in use, may be stacked up, so as to occupy very little space. They are commonly called **tote boxes.**

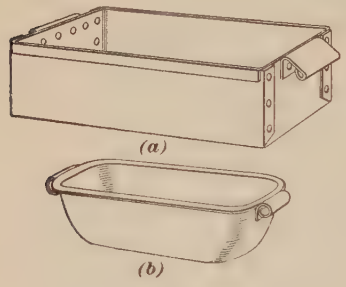

FIG. 1

26. Another useful and cleanly device is the **tray rack,** illustrated in Fig. 2. It consists of three iron trays, the upper one of which carries a drawer. It is especially useful where a number of operations have to be performed on pieces by different machines. The trays may be used by the machine-tool man to hold both the tools and work, while the drawer may contain his individual tools. Casters may be added to this rack, so that it may be moved from place to place with ease.

27. Waste Cans.—All waste or greasy material should be put in sheet-iron cans or barrels located at convenient points throughout the shop. These cans should be made of heavy galvanized iron or steel, and should have legs to keep their bottoms 2 or 3 inches above the floor. They should be riveted together, instead of being soldered, so that if the material in them should catch fire, they will not come apart and set fire to the building. A good tight-fitting cover should always be

kept on the can, so that if fire does start in the waste it will be smothered before gaining much headway. These cans should be taken out and emptied at stated times.

In some shops the dirty waste is washed and used again. The cleaning is done by putting the waste into a tank of water with soda, cheap soap, or some washing compound, and boiling it for a few hours by the use of either live or exhaust steam that enters the tank through a suitably arranged pipe.

28. Compressed-Air Hose.—In shops having compressed-air service, a $\frac{1}{2}$-inch rubber hose with a $\frac{3}{8}$-inch nozzle attached to it forms a convenient means of cleaning many pieces of work that are so shaped that it is difficult to reach every part with the hand. The blast is simply turned on the piece to be cleaned, and most, if not all, of the loose dirt is blown off. An air hose will be found very useful in the tool room for cleaning the shelves, racks, and drawers, and may even be used advantageously for rapid cleaning of some tools. The disadvantage of the air blast lies in the fact that it scatters the dirt all over the vicinity.

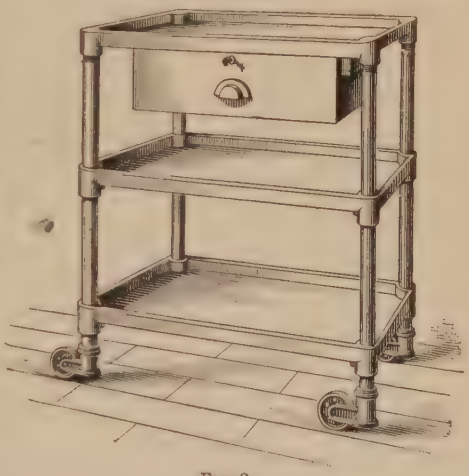

FIG. 2

29. Storing Devices.—Various methods are followed in caring for shop tools. Sometimes the tools are left where used until they are wanted for another job, when they are hunted for until found, and are then cleaned and made ready for use. This method is probably the worst that could possibly be devised, and is a direct evidence of mismanagement. The modern and proper plan is to require all tools to be cleaned by the user and returned to such a place as may be designated for their storage and care.

30. Tool rooms are built in most shops for the storage and care of all the tools used in the place; or, if the shop is divided into departments, each department may have its own tool room and a man to care for it, who, in addition, does such other work as he may have time for. The tool room may be used only as a storeroom for tools, or it may be equipped with such a varied selection of machines that any tool or appliance needed on the work may be made there, and tools and light machinery may be repaired. Large shops usually have, in addition to the tool room, such storerooms or vaults as may be needed for the storage of any large and valuable jigs, tools, or fixtures that are seldom needed, but require protection from fire. Tools should be so kept that they may be taken out and returned in the least time, and should also, while in their places, be well protected from dust and rust.

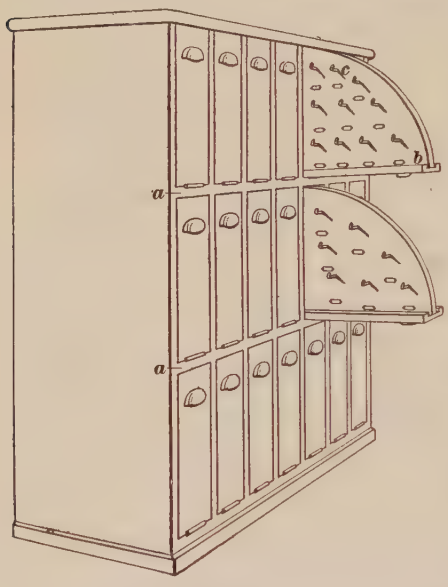

FIG. 3

31. Drawers are extensively used for holding tools, and for many purposes they answer admirably. They are, however, very liable to be overloaded, which treatment soon racks them to pieces. This may be avoided by making them extra heavy, or providing rollers for them to run on. They may also be easily handled if the sliding surfaces are of hardwood or are metal-faced, and the contact surfaces are greased occasionally with a good lubricating grease. Drawers are used to the best advantage for tools which are seldom needed but require protection from injury and dirt.

32. Shelves or pigeon-holes furnish the most ready means of keeping tools that are much used. These should be as shallow as possible in order that the tools may not be pushed in out of sight, and that they may be easily brushed out, or blown out if an air hose is used for cleaning. Cupboards containing numerous shelves are useful for special tools used less frequently than standard ones, since the cupboard doors protect them from dirt and the atmosphere.

33. The walls of tool storerooms are often covered with boards, which are painted and have hardwood pegs put into them on which to hang milling cutters and similar tools; in some cases, nails are used instead of the wooden pegs. It is better to keep the cutters in the form of cabinet shown in Fig. 3, which cabinet has a series of shelves *a* to which boards *b* are hinged. These boards are provided with hooks *c* on which to hang the cutters. This cabinet provides a clean, convenient, and space-economizing place for a large number of milling cutters and gear cutters.

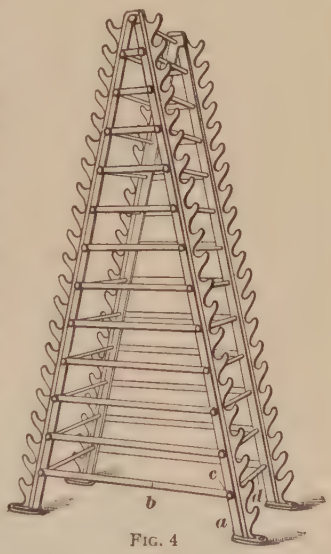

FIG. 4

34. Racks of various kinds furnish a convenient and clean place for keeping a large class of tools, such as pipe stocks, wrenches, long taps, reamers, drills, boring bars, cutter bars, sockets, and other similar long tools, in such a manner that they are easily put away or gotten out, and are kept clean when in their places. A rack of this description is shown in Fig. 4. It consists of four uprights *a* that are braced by wrought-iron tie-bars *b*. The tie-bars are fastened to the uprights by long bolts *c*, which pass through them at each end. The bolts are surrounded by distance pieces *d* made of iron pipe, which keep the uprights separated.

35. Racks that are constructed as shown in Fig. 4 may be made 7 feet high and $3\frac{1}{2}$ feet wide at the base, with the uprights spaced at such distances as will accommodate the shortest tools that may be kept on them. Light and frequently used tools are piled on the arms, while less used and heavier tools are placed on the cross-pieces *b*. These racks may stand against the wall, but are preferably placed on the floor where they can be reached from all sides. Racks of special design are usually provided for such tools as ratchets, tapping attachments, air drills, and other portable drilling and grinding fixtures.

Boxes are sometimes used for storing tools, and when so used they should be plainly marked; a convenient record should also be kept of their exact contents.

36. Rams.—When taking old machinery apart—as, for instance, when trying to remove an old shaft from a wheel or crank—the heaviest blow possible must sometimes be struck. The heavy blow carries the object struck before it, while lighter blows will simply upset the end of the piece and thus rivet it into place. When heavy sledge hammers are used on light work, the surfaces hammered should be protected by a piece of Babbitt metal or copper held or laid on them.

Where heavier blows are required than can be struck with a sledge, a ram is used. This device is a long bar of iron suspended at its center of gravity, in order that it may hang in a horizontal position, and hung in front of the piece to be rammed. The rope suspending the ram is made fast to an overhead point, after which the operators draw the bar, or ram, backwards as far as possible, and then run with it toward the piece to be struck. The ram is often used when a hydraulic press is not available or suitable for the work. Care should be taken in using the ram not to upset the face of the part that is being rammed, as this will tighten the parts in their places. Several men are required to operate a heavy ram, which is expensive and should not be resorted to if a press can be used.

37. Soda Kettle.—All shops have more or less work that must be cleaned so as to be free from grease. This is often a

troublesome task, involving the expenditure of time and energy. The greater the irregularity of the pieces, the more trouble it is to clean them.

A very convenient method of quickly and easily cleaning small parts of machines, tools, or machined parts is to wash them in hot soda water. The most convenient receptacle for this mixture is known in the shop as a soda kettle, which is often a shop-made affair, but embodies the main features of the kettle illustrated in Fig. 5. This soda kettle consists of a cast-iron kettle *a* containing a coil of steam pipe for heating the soda water. Live steam enters the coil when the globe valve *b* is opened, and the exhaust steam leaves through the pipe *c*, which is provided with a globe valve. A by-pass pipe *d* having a globe valve connects the exhaust pipe to the kettle; if the globe valve in the exhaust pipe is closed and the valve in the by-pass pipe is opened, the pressure of the live steam will force the water of condensation in the bottom of the coil into the kettle. By opening the drain cock *e* the kettle may be emptied.

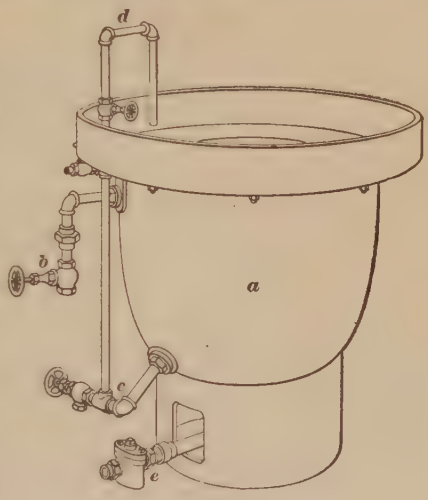

FIG. 5

38. In use, the kettle is filled about three-fourths full of clean water to which is added about $\frac{1}{20}$ its volume of sal soda; the mixture is then heated as hot as the steam will heat it. A wire basket, or an iron pail, or bucket, having the bottom punched full of holes, is provided for holding small pieces while dipping them into the soda mixture. Suitable hooks made of small iron rod may be used to dip single pieces into the kettle.

A pair of pick-up tongs and one or two hooks should be kept near the kettle, since pieces are sometimes dropped into it and must be fished out. Work covered with soft grease or oil and chips is cleaned by putting it into the basket, which is then dipped into the hot liquid. Work covered with oil that has dried on it often has to be soaked in the solution for some time, and a part of the dried oil then has to be scraped off; the work is now given a further soaking, which is generally sufficient to remove the rest of the dried oil. Work cleaned in hot soda water dries quickly and the soda water will not rust it.

GENERAL SHOP PROCESSES

BELTING AND SHAFTING

PULLEY SIDE OF BELT

39. Oak-tanned, fulled leather belting is the kind commonly used in shop practice. It is made of ox hide by a tanning process. The side of the hide that was next to the flesh of the animal is known as the *flesh side*, and the other side as the *hair*, or *grain*, ***side.*** The grain side of the belt is harder and weaker and will crack easier than the flesh side. It will, however, stand more crimping than the flesh side, and the grain side is run next to the pulleys. By running the grain side next to the pulleys the tendency is to cramp, or compress, it as it passes over the pulley, while if it ran on the outside, the tendency would be for it to stretch and crack. Moreover, as the flesh side is the stronger, the life of the belt will be longer if the wear comes on the weaker or grain side.

40. Belts may be *single*, *double*, *triple*, or *quadruple*. A single belt consists of a single ply of leather, a double belt of two plies, etc. The two plies of a double belt are placed with the flesh sides together, and consequently either side of a double belt may be run against the pulley. Similarly, the triple

and quadruple belts are so arranged that the grain sides of the outer plies are exposed and they may be run with either side in contact with the pulleys. When crossed belts are used, care must be taken to put on the belt so that the grain side will be in contact with both pulleys, it being possible to put a crossed belt on in such a way that the grain side will be in contact with one pulley and the flesh side with the other.

FASTENING AND CARE OF BELTING

41. Cemented Belt Splices.—The cemented splice, Fig. 6 (*a*), is the most durable of all belt-fastening methods.

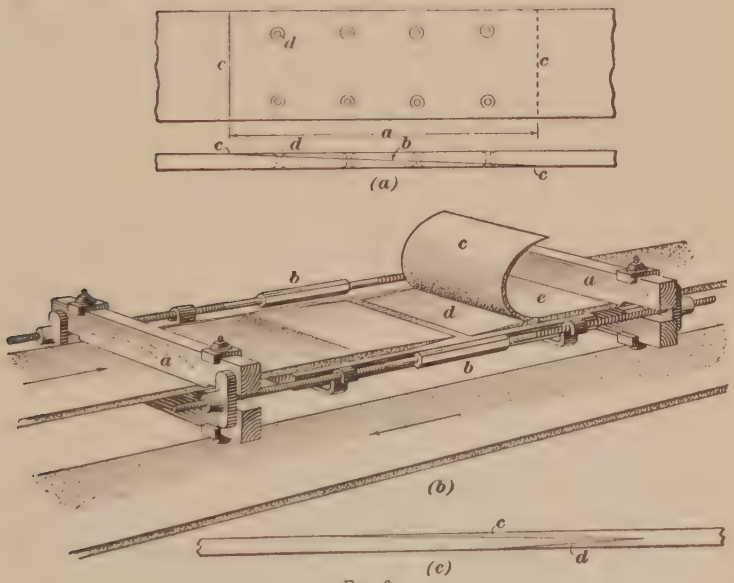

FIG. 6

As belts usually give out at the point where they are fastened together, it is thought by some shop men that all belts should be joined by the cemented splice. Unless, however, some provision is made for adjusting the center distance between pulleys as the belt stretches, at least one other form of splice must be used in the belt.

The length *a* of the cemented splice varies from about 9 to 18 inches. Belts 9 inches in width and narrower have splices 9 inches long, and belts greater than 9 inches in width have splices as long as the belt is wide. However, no splice is made longer than 18 inches.

The belt is first cut off the required length, making the proper allowance for the length of splice, after which one end of the belt is tapered, as shown at *b*, using a small block plane. The ends are tapered in the same direction as the corresponding parts of other splices, if there are any in the belt. If there are no other splices in the belt, the end is tapered in such a way that the feather edge *c* of the pulley side of belt will point away from the pulley it is approaching and the grain side of the belt will be in contact with the pulleys. The position of the lap is marked off on the other end of the belt and this end is cut similarly. Both ends are now scraped smooth with a piece of glass, called a *slicker*.

42. A thin coating of belt glue, known as *sizing*, is next applied to the surfaces to be cemented, after which the cement is put on rapidly, and the laps are immediately brought together and hammered all over with a shoemaker's hammer. Rubber-faced shoes—that is, flat boards faced with rubber—are now brought against the splices, hand clamps are applied to them, and the splice is squeezed hard between the shoes.

The splice is allowed to set for from 15 minutes to 1 hour, when the clamps are removed, and shoemaker's nails are driven through the splice about $\frac{1}{2}$ inch apart. The cement used should be rather hot. It may be made by mixing Le Page's liquid fish glue and Russian liquid isinglass in the proportions of 2 to 1, by measure. If the cementing is done in a cold room, burning paper may be passed back and forth over the laps to warm them before applying the cement, which should be about as thick as ordinary glue. Instead of shoemaker's nails, iron or copper rivets *d*, preferably iron, are sometimes used to reinforce the splice.

43. Sometimes a belt must be cemented together in position on the pulleys. In that case a belt tightener, Fig. 6 (*b*), must

be used to hold the belt in position while making the splice. The clamps *a* of the tightener are secured to the belt, which is tightened to the desired tension by means of the screws *b*. The belt is located in the center of the clamps, which are square with the belt. The belt is drawn a little tighter than a running tension. The joint is spliced and cemented in the usual way, or one end may be spliced **V**-shaped as shown at *c*, to receive the other end of the belt which is wedged into the **V**. This is an alternate method for making a cemented splice. A little longer time is required to complete the work; but it has the advantage over the preceding method in that when the feather edge *d* is pointing away from the pulley to which it is advancing, the feather edge *c* on the outside of the belt is not running against the air, which would tend to force the splice open. The finished splice is shown in (*c*).

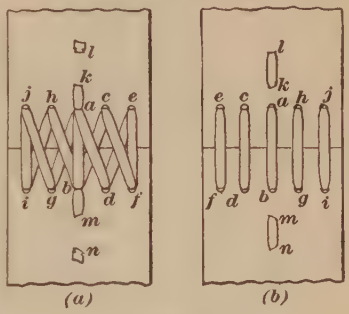

FIG. 7

44. Laced Joint.—There are many ways of making a laced joint. Whichever method is used, the usual practice is to place all holes at least from $\frac{1}{2}$ to 1 inch from the edge and end of the belts, to space the holes uniformly, about 1 inch apart, and to lace the joint so that the pull on the lace will be in line with the center line of the belt. The lace is cut into strips of the necessary length and varying in width from $\frac{1}{4}$ inch up, depending on the size and the form of the joint. The holes are made in the belt with a lace punch, and the lace is pushed through the hole with an awl or pulled through with a pair of pincers. The smoother side of the joint is generally run next to the pulley and the stronger side on the outside, the greatest force acting on this part of the joint. In all cases it is essential that the ends of the belt be squared up with a try square before lacing.

45. The outside of a standard form of laced joint is shown in Fig. 7 (*a*), and the pulley side of the same joint in (*b*). An

odd number of holes is required in each end of the belt for this joint, the total number depending on the width of the belt to be laced. The holes on each end must be exactly opposite the corresponding holes in the other end. To lace the joint, the lacing is put through the middle holes *a* and *b* from the pulley side of the belt and drawn taut against the belt in such a manner that the extending ends will be equal. The lower end of the lace in (*a*) is now passed through *c*, *d*, *e*, *f*, *e* again, *f*, and *c*. The other end of the lace is next passed through *g*, *h*, *i*, *j*, *i* again, *j*, *g*, *h*, *b*, and *a*. The first end of the lace is then passed through *d*, *a*, and *b*. The lacing is now adjusted until the ends of the belt butt tightly against each other and all the looseness in the lace is taken up, after which the lacing is passed through the holes *k*, *l*, *m*, and *n* as shown. The ends are cut off near the belt, and then cut slightly close to the belt, which makes a notch, so that the part beyond the belt will catch and be held from moving farther.

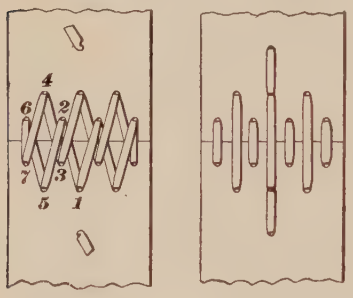

FIG. 8

46. In Fig. 8 is illustrated a method of lacing, in which double rows of holes are used, (*a*) being the outside and (*b*) the pulley side of the belt. The lacing for the left side is begun at *1*, and continues through *2*, *3*, *4*, *5*, *6*, *7*, *4*, *5*, etc. A 6-inch belt should have seven holes, four in the row nearest the end; and a 10-inch belt should have nine holes, five in the row nearest the end.

47. Wire-Laced Joint.—Belts are frequently joined with wire lacing. A joint made in this way is shown in Fig. 9 (*a*). It consists of coiled wire *a* inserted in each end of the belt and a rawhide pin *b* that holds the wires together. The wire is helical, having a pitch of about $\frac{1}{6}$ inch, is flattened to a thickness not greater than the thickness of the belt, and has its ends bent back into the belt, so as not to catch and tear the hands in shifting. The lacing is wound into the belt by a special machine.

The wire-laced joint is strong and flexible, though not so strong as the cemented splice; also, it has the advantage that it may be quickly connected and disconnected, the insertion or removal of the rawhide pin being all that is required to make or break the joint.

New belts stretch considerably. For this reason, the belt may be cut shorter than the desired length by about 4 inches and a 4-inch filler *c* inserted in this space. When the belt stretches, a 2-inch filler is substituted and then a 1-inch filler, until the belt is stretched its nominal amount and the main ends come together. The fillers may be kept in the stock room and used repeatedly.

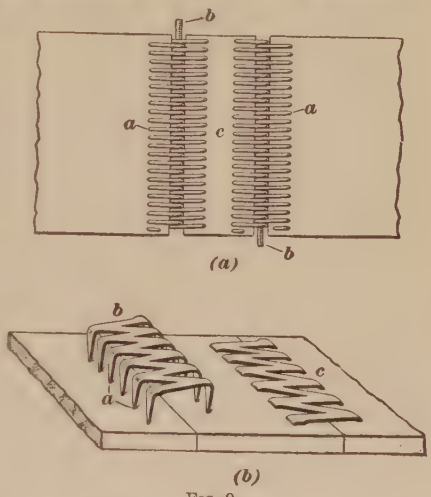

FIG. 9

48. Metal Belt Fasteners.—Many types of metal belt fasteners are in use. Their chief advantage lies in the fact that they can be quickly attached to a belt, as well as quickly removed from it. In using any type of metal fastener, the abutting ends of the belt should be carefully squared before the fasteners are applied. In Fig. 9 (*b*) is shown one form of metal belt fastener. When applying this fastener, no holes are needed in the belt, as the prongs, or points, *a* are so shaped that they will cut their way through the belt material. The fastener is shown ready to apply at *b*, and the finished joint is shown at *c*. After driving the fasteners through the belt, the prongs are clinched on the opposite, or pulley, side of the belt.

49. Tension of Belting.—Good oak-tanned belting about $\frac{3}{16}$ inch thick should be tightened to a tension of about 40 to 50 pounds per inch of width. The tension to which belts of

different thicknesses should be tightened may be found by dividing the thickness of the belt by $\frac{3}{16}$ and multiplying the result by 40 or 50, as desired. If belts $\frac{3}{16}$ inch thick are tightened to a tension of 50 pounds, a greater load may be carried than could be done if tightened to a tension of 40 pounds; but the wear and tear on the belt will also be greater and the belt will not last so long.

Tension scales by the use of which belts can be set to the desired tension are to be had. Belts are most commonly fastened without the use of tension scales. In this case, care should be taken not to have the belt too tight, as serious wear on the pulley bearings and injury to the belt might ensue. On the other hand, the belt should be tight enough to carry its normal load. A good rule to follow is to tighten the belt so that it will give slightly under pressure from the hand.

50. Length and Retightening of Belts.—When putting on new belting, the length to which the belt is to be cut may be found by measuring the distance around the pulleys with a tape and subtracting from this result $\frac{1}{8}$ inch for every foot of length. New belts must usually be tightened every day for a time, after which the intervals may be gradually increased to 2 days a week, and finally to from 3 to 6 months, depending on the severity of the service. The time between retightening may be greatly lengthened by throwing the belt off its pulleys when not in use.

51. Greasing of Belts.—A new belt contains a certain amount of oil that makes it pliable and gives it a clean, pulling surface. After the belt is in use for some time, this oil becomes spent and to keep the belt in good working condition some form of oil or grease must be supplied. A very serviceable grease is a mixture of 2 parts, by weight, of pure beef tallow and 1 pint of cod-liver oil. In preparing the grease, the tallow is melted and allowed to cool until one can put his finger in it without being burned; then the cod-liver oil is added and the mixture stirred until cold. A number of good belt greases under various names are on the market. Belts should be scraped clean and greased about every 6 months.

52. Dressing and Cleaning of Belts.—From various causes, belts often slip when in use. In these cases, resin is sometimes applied to the surface of the belt; but it should never be used, as it ruins the belt, which in a short time will slip worse than before. Belt dressings should be applied sparingly, too much being often worse than none at all. They are not preservatives, and should be used only in emergencies.

53. Extreme care should be taken to prevent belting from becoming saturated with oil, which is liable to work its way to the belting from the shafting and bearings. When belts become oil-soaked, they should be cleaned by wiping with waste and scraping off the oil, after which they may be run through a pair of rollers under pressure. The rollers will squeeze out the oil, which should be absorbed by powdered chalk. If no rollers are available, the belt may be packed in sawdust, for from 2 to 7 days, after which it may be cleaned and used.

LINING OF SHAFTING

54. Line shafting may be either suspended from roofs, ceilings, walls, or columns, or supported from floors; by far the larger portion is suspended from roofs and ceilings. The methods of erecting are, in general, the same for all; but the details usually vary more or less with each installation and the care in carrying out these details determines the subsequent smooth running of the shafting. Aside from the structural work, the various parts entering into a section of shafting are *hangers*, *bearings* and *boxes*, *shafting*, *couplings*, *collars*, *girder clamps*, *pulleys*, and *belt-shifting devices*. Some of these parts are shown in Fig. 10. In (*a*) is shown a hanger *a* attached to the I beam *b* by means of the girder clamps *c*. The bearing box *d* and cover *e* are shown in position. To adjust the height of the bearing, the screws *f* are loosened; the box and cover are then raised or lowered as desired and secured in position by tightening the screws *f*. Hangers are, as a rule, attached to I beams only when used to support main shafts, owing to the rather long distance between them. When employed to

support countershafts, secondary beams are generally connected to adjoining **I** beams and the hangers are bolted to these in any convenient manner.

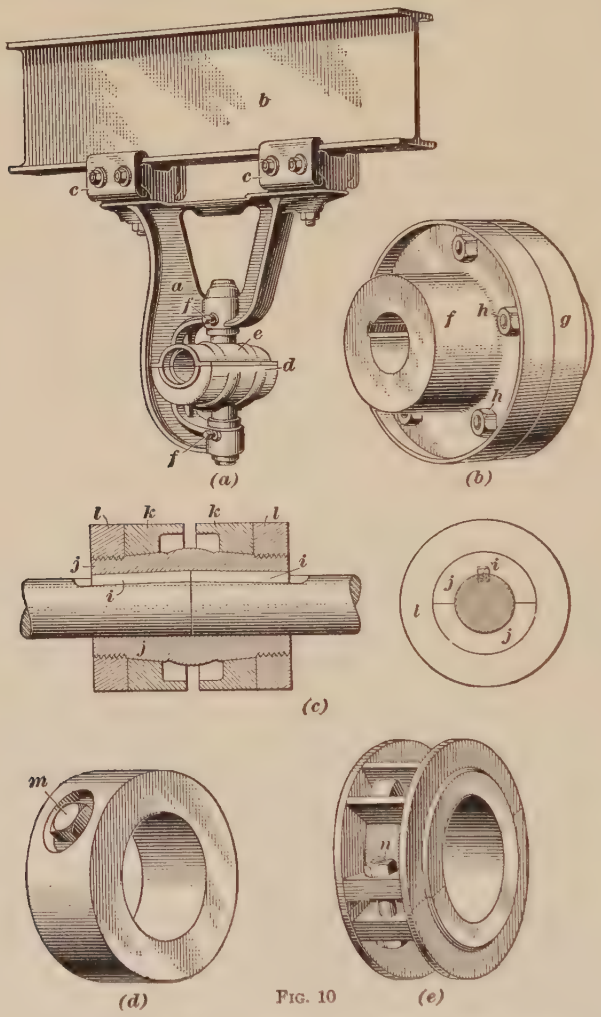

FIG. 10

55. Couplings are used to join sections of shafting. The *flanged coupling* is shown in Fig. 10 (*b*). The part *f* of this coupling is keyed to the end of one shaft, the part *g* to the other,

and both parts are clamped together in position by means of the bolts and nuts *h*. The *compression coupling* is shown in (*c*). It consists of two keys *i*, two half clamps *j*, two tapered rings *k*, and two threaded rings *l*. When setting this coupling in position, the keys are first fitted to the shafting, the half clamps are then placed over them, and the taper rings are slid over the clamps. The threaded rings are next screwed on the threaded ends of the half clamps, forcing the tapered rings home and completing the connection.

56. Collars are put on the shafting to prevent it from working endwise in the bearings. A *solid collar* is shown at Fig. 10 (*d*). It is secured to the shaft by tightening the set-screw *m*. A *split collar* is illustrated at (*e*). It is made in two pieces and can be put on any part of the shaft without slipping it over the end. It is secured in position by means of the bolts and nuts *n*. The collars may be separated from the bearing boxes by a fiber washer.

57. Erection of Main Shafts.—A method of supporting shafting from wooden girders is shown in Fig. 11. This is the method that is used to support shafting in the older types of buildings and in new buildings where a low first cost is of prime importance In modern structures, however, the hangers are supported by metal girders.

58. A straight line *a b*, Fig. 11, is first made along the ceiling of the building or on the bottom of the horizontal girders *c* by stretching a chalked line tightly and then snapping it on the ceiling or girders. This line is stretched parallel to the nearest wall or to the nearest row of vertical girders and as nearly as possible at the distance from the wall the shaft is to be located. The position of the line may be located readily by measuring off at right angles to the wall or girders an amount at the beginning and end of the section the shaft is to occupy equal to the distance the shaft is to be from the wall or girders. The stringers *d* are now bolted to the horizontal girders *c*. These stringers are located on opposite sides of, and parallel to, the line *a b*, and are spaced a distance apart sufficient to accommodate the hangers.

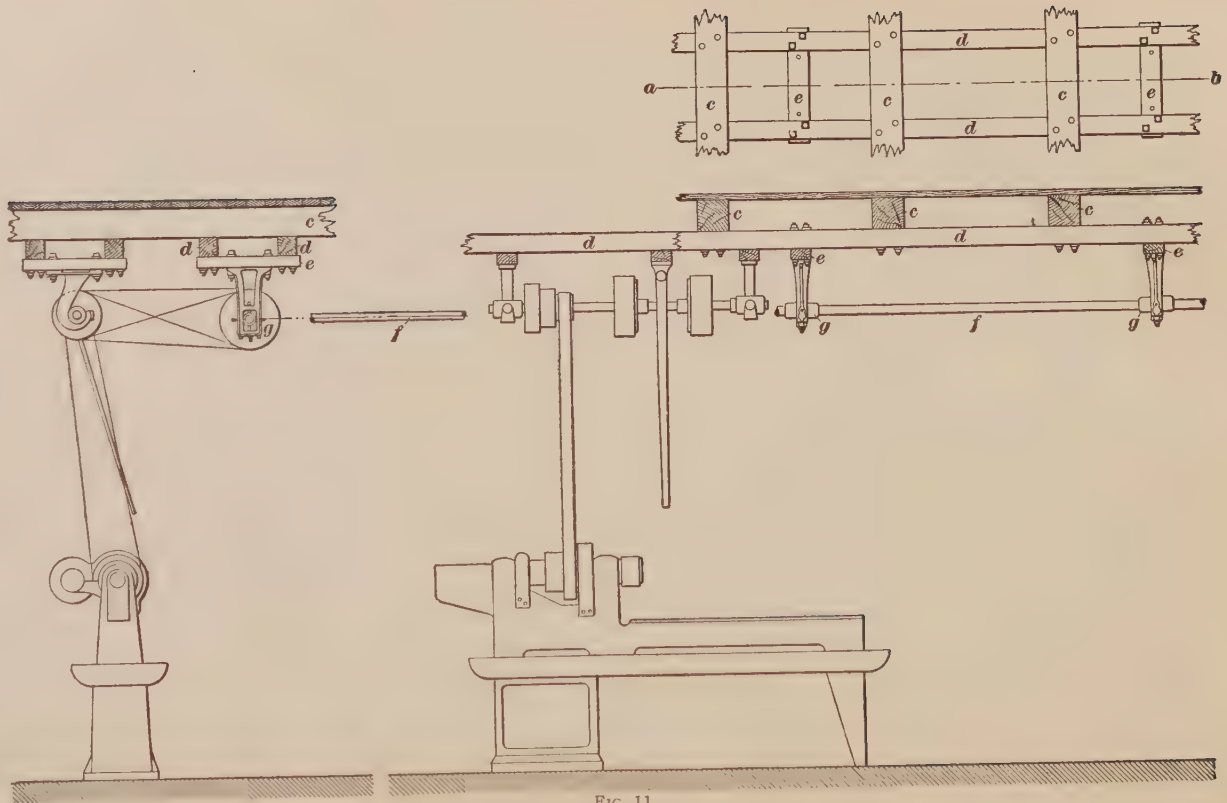

FIG. 11

The footing pieces *e* for the support of the hangers are next bolted to the stringers, the distance between them for ordinary work being from 8 to 10 feet. The hangers are bolted quite loosely to the footing pieces. The shafting *f*, which is usually in 24-foot lengths, is then lifted into the hangers. The bearing boxes *g* are now adjusted and, if necessary, the hangers are moved horizontally either way from their original position to accommodate the shafting properly, after which the couplings on adjoining lengths of shafting are connected up, thus forming a continuous piece. A line is now stretched parallel to two lengths of the shafting, in a horizontal plane with it, and about 12 inches from it. This line is secured to pins or nails set near the ends of short sticks, which are nailed to the ends of the footing pieces. The line is so set that it is the same distance from the extreme ends of two adjoining pieces of shafting. The intermediate portion of these parts of shafting is then made parallel to this line by adjustment of the intermediate hanger. This operation is repeated for every length of shafting, each hanger being bolted tightly in position after adjustment.

When all the shafting is in place, the various lengths are leveled by placing a spirit level along the top of each length and moving the adjusting screws on the bearing boxes up or down, as may be necessary, locking the screws into position when finally adjusted. Precaution must be taken to place the required collars, if the solid or flanged type of coupling is used, or the rings, if the compression type of coupling is employed, on the shafting before erecting.

59. Erection of Countershafts.—The countershaft is erected in practically the same way as the main-line shafting. The machine is, however, first set in its proper position on the floor and the countershaft is placed temporarily on the floor directly under the position it is to occupy overhead. The machine and countershaft are now shifted until a position is found for the countershaft in which there will be no interference overhead by other shafting. A plumb-line is then dropped from the roof or ceiling to the machine and the point on the ceiling from which it is dropped is marked. From this

point the erection of the countershaft is then proceeded with. The countershaft is erected parallel to the main-line shaft in much the same manner as the latter was originally made parallel with the wall of the building; and the machine is plumbed from the main-line shaft, or it is alined by sighting along some suitable objects such as a line of columns, other machines in the vicinity, or in various other ways.

Whether the belting connecting the machine with the countershaft is exactly vertical, at an angle, or with a twist, depends almost entirely on the construction of the machine tool, it being largely a matter of the belting clearing all parts of the machine.

BABBITTING

PRINCIPLES, PROCESSES, AND DEVICES

60. Babbitting, as is generally understood, is the process of lining a wearing surface or journal, for the purpose of reducing friction, with **Babbitt,** which is a soft, metal alloy containing varying quantities of lead, copper, tin, zinc, and antimony. Babbitts, or Babbitt metals, are divided into two classes, for heavy and light service, respectively, tin predominating in the former and lead in the latter.

The babbitting process is also used in the keying, or holding, of one piece of apparatus to another, the balancing of rotating parts, the plugging of holes, etc. The lining of journal bearings, however, is the most common application of the process of babbitting and, while exceedingly simple in itself, certain steps must be carefully followed to insure success.

61. Composition of Babbitt Metal.—There are many combinations of Babbitt, each having some particular feature to recommend it. The prices of Babbitts vary greatly, depending on its percentages of tin and copper, these two metals being the highest in value of its constituents. It is therefore well to base the selection of a Babbitt on a knowledge of the purpose for which it is intended, and it is usually the part of wisdom to

purchase the Babbitt already made instead of attempting to make this metal, since there are many points in its manufacture requiring the knowledge of experts.

62. In the best grades of Babbitt, tin is the principal constituent, antimony is next in importance, and copper follows. Antimony gives hardness to the Babbitt, while tin gives it its antifriction qualities. In the cheaper grades of Babbitt, lead is used. Lead is unsurpassed for antifriction qualities, but is too soft to be used alone; for light, fast-running journals it may be employed when alloyed with antimony or antimony and tin.

For hard service, the following composition may be used: Tin 90 per cent., copper 2 per cent., and antimony 8 per cent., by weight.

For light service, the following composition may be used: Lead $83\frac{1}{3}$ per cent., tin $8\frac{1}{3}$ per cent., and antimony $8\frac{1}{3}$ per cent., by weight. The first alloy should be poured at about 800° F. and the second at 900° F., but where both are in constant use they are poured at about 860° F. The melted lead base Babbitt is sluggish, sets quickly, and must be poured at a high temperature.

63. Melting Babbitt Metal.—Care must be taken in melting Babbitt to heat it slowly. The surface of the melting metal is covered with powdered charcoal, to prevent oxidation of the tin and antimony, and the Babbitt is stirred with a dry pine stick, which is a guide to the temperature of the Babbitt, since the metal must not become so hot as to char the pine. An occasional job can be babbitted by metal melted in an iron ladle over a blacksmith's fire, but in larger establishments the steady employment of several men with special fires and appliances is often required. Babbitt metal should never be melted over a blacksmith's fire that is to be used for welding, for if a little of it gets into the fire, it is likely to spoil the welds.

64. A fire should be set apart for melting Babbitt. A portable forge is especially useful for this work, as it can be moved to the place where the work is to be done. Coke is preferable to coal for melting Babbitt, as it makes less smoke. Gas is also an excellent fuel for this purpose. A form of Babbitt

pot heated by gas is shown in Fig. 12. The gas passes through the pipe *a* to a burner, the crucible *b* receives the Babbitt to be melted, and the gas is lighted through the door *c*.

65. The ladles may be either of wrought iron, steel, or cast iron, and may be of either the plain or the self-skimming type. They should be discarded when worn thin at the bottom, as metal may be lost by an unnoticed leak. Two forms of self-skimming ladles are shown in Fig. 13. The one shown at (*a*) has the spout located at the bottom of the ladle, while that shown

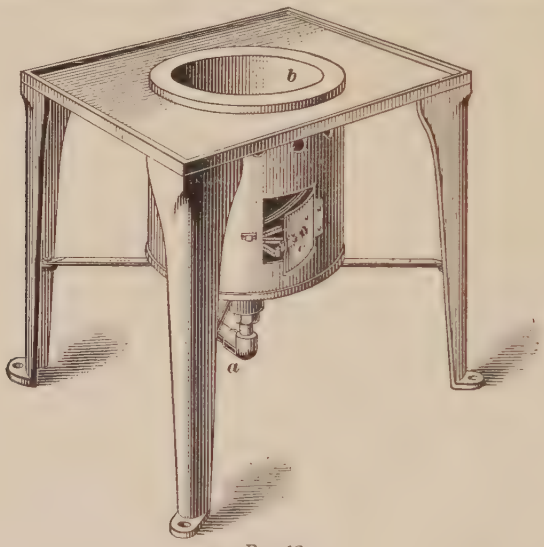

FIG. 12

in (*b*) is provided with a covered spout. These spout constructions tend not only to keep out the dross when the ladles are being filled by immersion in the Babbitt pot, but also to hold back within themselves any dross that may have been collected in the filling and to prevent it from entering the casting during the pouring. By *dross* is meant the oxides that accumulate on the surface of the molten metal, owing to its contact with the air.

66. For large work, the melting is usually done in either a cast-iron kettle or a boiler-iron ladle set in a brick furnace. The

surface of the metal when melting should be covered with powdered charcoal to exclude the air in order to prevent excessive oxidation. The melted metal is dipped out of the melting pot in hand ladles, from which it is poured into the boxes. When dipping the ladle into the pot, it should be done slowly in order to bring the ladle gradually to the temperature of the Babbitt, thus precluding chilling of the Babbitt if the pot be a small one, as well as avoiding any risk of spattering the Babbitt if there should be any moisture or grease on the ladle. A little powdered resin should be scattered on the surface of the

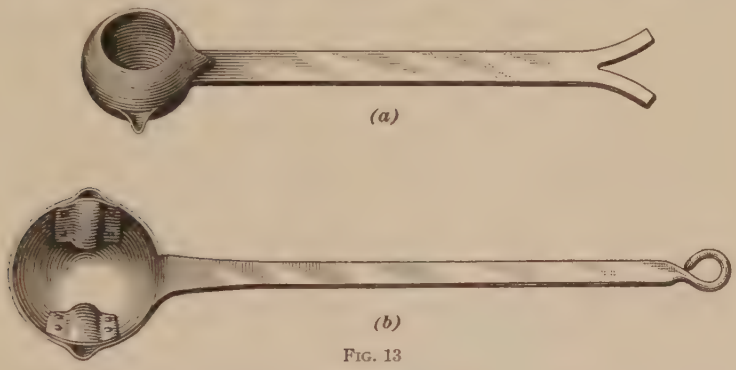

FIG. 13

metal and the metal stirred with a stick just before pouring. The rosin acts as a flux and leaves the metal cleaner and more fluid.

67. Form of Box for Babbitting.—The Babbitt metal in boxes or bearings is generally held in place by raised strips or projections cast in the box, which enclose it on all sides, for the purpose of restraining the tendency of the metal to stretch or flow under the pressure or pounding of the shaft. The strips should be cut below the surface of the bearing, to avoid contact with the journal. In the case of large boxes, dovetail grooves are sometimes cast in the surface of the casting to aid the strips in holding the Babbitt; in some case the strips are omitted, and the dovetail grooves only are relied on to hold the metal.

68. Compressing Babbitt Metal Into Place.—All metals expand when heated and contract when cooled; but Bab-

bitt metal expands and contracts a greater amount than the boxes in which it is usually cast. Heating the box before pouring the Babbitt in it will reduce the difference between the amounts the Babbitt and box will contract after cooling. For this reason, when a good bearing is desired, it is babbitted smaller than the finished size, and the Babbitt is compressed into its place in the box. Important journal-boxes like those in the pillow-blocks of an engine are generally babbitted from $\frac{1}{8}$ to $\frac{1}{4}$ inch smaller than the finished bore. The metal is then hammered into the box by using the round peen of a hammer to either compress or expand it firmly into place, after which the bearing is bored to the required diameter.

69. Roller tools, illustrated in Fig. 14, may be used to advantage for compressing Babbitt into place. If the Babbitt bearing is chucked in a lathe, the tool (*a*) is used in the tool post and fed through the work after the manner of a boring tool; or, if a boring bar is used, the tool (*b*) may be inserted in the bar or cutter head and takes the place of a boring tool. The feed and speed of the roll may be considerably faster than in the case of a boring tool. The surface to be rolled may be lubricated with soda water, soap water, or oil. In the case of small bearings, the metal is compressed by driving or forcing one or more polished steel drift plugs through the bearing.

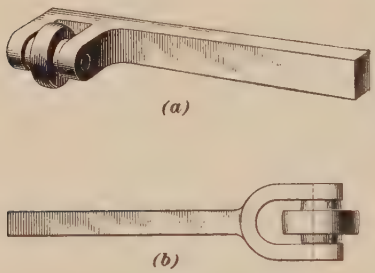

FIG. 14

70. Mandrels for Babbitting.—A mandrel is placed in the box when the Babbitt is poured. If the Babbitt is to be compressed and bored, this mandrel is made smaller in diameter than the shaft for which the box is constructed; otherwise, it is made of the same diameter as the shaft. The mandrels are often made hollow, as shown in Fig. 15, and consist of a cylindrical portion *a* with a bar *b* across each end. The bars *b* carry the centers *c* for turning the mandrel in a lathe. The hollow

mandrel is not only cheaper than a solid one, but is also lighter to handle and quicker to heat in case it must be warmed before pouring the Babbitt. Mandrels are also made of wood. Iron mandrels should always be warmed before the metal is poured into the box.

The mandrels are often made a little larger than the journal that is to be used in the box, both to allow for the shrinkage of the box and to insure that the bearing will not bind the shaft sidewise; a box that bears in the bottom is less likely to heat than one that pinches the shaft sidewise. Sometimes the journal is used instead of a mandrel, paper being wrapped around it; this is not advisable except in repair work which must be done quickly.

71. Babbitting Process.—A proper thickness of Babbitt may be obtained by supporting the mandrel on pieces of pasteboard or wood, which are placed on the strips that retain the Babbitt in the box. To prevent the Babbitt from running out at the ends and joints of the box, the openings should be closed with clay or putty; care should be taken that they are not too wet, as water in the mold is likely to form steam and blow out the metal. A pouring basin leading to the box may also be made of clay or putty; large boxes are sometimes poured from several ladles simultaneously. In all cases, ample vents should be left for the air to escape from the box, and the metal should be poured at a low heat and as rapidly as possible. The surface of the mandrel should be slightly oiled.

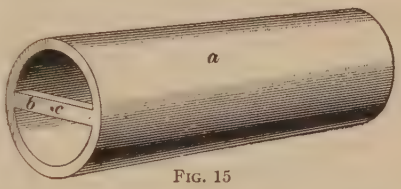

FIG. 15

72. When babbitting cast- or malleable-iron bearings, the rough casting must first be thoroughly cleaned and the anchor holes well freed from foundry sand, which may be accomplished either by *brushing*, *sand blasting*, or *pickling*. When sand blasting, a jet of sand is directed on the work with great force; and when pickling, the work is washed in a dilute acid, as for example, 1 part of sulphuric acid to 4 or 5 parts of water,

and the castings are permitted to soak until all the scale or sand has become loosened and has fallen off. The casting must next be washed in water, preferably hot, and no trace of acid allowed to remain; otherwise, it will continue to eat its way into the casting and eventually loosen the Babbitt in the finished bearing. Another point to be carefully observed is to dry the casting thoroughly, especially in the anchor holes. Even the smallest amount of moisture is liable to cause an explosion, scattering the molten metal and perhaps burning the workmen, when, in pouring, the hot Babbitt comes in contact with the wet casting.

73. Whenever possible, both the casting and the mandrel should be heated to approximately the temperature of the Babbitt before pouring. The casting may either be placed in an oven especially provided for this purpose, or it may be set on the rim of the Babbitt pot until well heated, then immersed in the pot for a few minutes, after which it is withdrawn and made ready for babbitting. The mandrel may be treated in like manner, though after once heating, the contact with the molten metal, as each bearing is poured, will keep it sufficiently hot. This preliminary heating tends to reduce shrinkage of the Babbitt when it comes in contact with the cooler walls of the casting and the mandrel. Any cored holes in the casting should be fitted before pouring, with metal or wooden plugs and the crevices closed by a mud of fireclay, so as to retain the Babbitt during the pouring. After babbitting, the plugs and the mandrel are removed, and all fins or surplus Babbitt trimmed away with a hot soldering iron. The bearing is then further machined, being sometimes turned or broached on the inside, though machining is not always necessary. It is, however, usually placed on a mandrel or arbor and turned on the outside as well as faced at both ends. The oil grooves, if they have not been cast in the Babbitt at the time of pouring, are next cut and the dowel-pin holes drilled or the keyway slotted.

EXAMPLES OF BABBITTING

74. Babbitting a Plain Box.—Suppose a plain box is to be babbitted. A mandrel of the form shown in Fig. 16 may then be used when pouring its upper and lower parts. This mandrel consists of a cylinder *a* of the required diameter and length, with a disk *b* at each end to fit against the machined ends of the box. One disk is held in place by a cap screw *c* and is removable. The mandrel is first put in position in the bottom of the box and Babbitt is poured in the lower half of it. The top of the lower half is then finished, and the work is set up again, liners of pasteboard or sheet iron being placed between the halves of the box to prevent the Babbitt of the upper half from running into that of the lower half when poured. The Babbitt is poured through the oil holes or slot in the cap. Should blowholes be found in the Babbitt lining, they may be filled with the aid of a hot iron and a stick of Babbitt of the same composition as that used in the bearing.

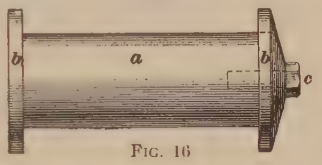

FIG. 16

75. Jig Method of Babbitting a Box.—The bearing box *a*, Fig. 17 (*a*), may be babbitted by the use of a babbitting jig (*b*) and (*c*). The jig consists of a base *b*, four side pieces *d*, *e*, *f*, and *g*, which fit on the sides of a central core *h*, and a collar *i*. The core and the four side pieces are tapered on the abutting sides, so that after pouring, the core may be withdrawn, and the side pieces allowed to collapse and be also withdrawn. The purpose of the collar is simply to hold the side pieces to the core before pouring. When setting up the jig, one end of the core *h* is placed in the bore *j* of the base *b*, the side pieces *d*, *e*, *f*, and *g* are placed in the bore *k*, the bearing *a* is put over the core and side pieces, and the collar *i*, by which the upper ends of the side pieces are held against the core, is placed in position as shown in (*b*). The Babbitt is poured around the core through the opening *l*.

76. Babbitting Pillow-Blocks of Engine.—In Fig. 18 is shown a rig for babbitting the pillow-blocks of a center-crank

engine, (*a*) being a side view and (*b*) an end view. The engine frame *a* rests on the parallels *b*, which are supported by a cast-iron floor plate *c*. The parallel *b* under the pillow-block *d* is

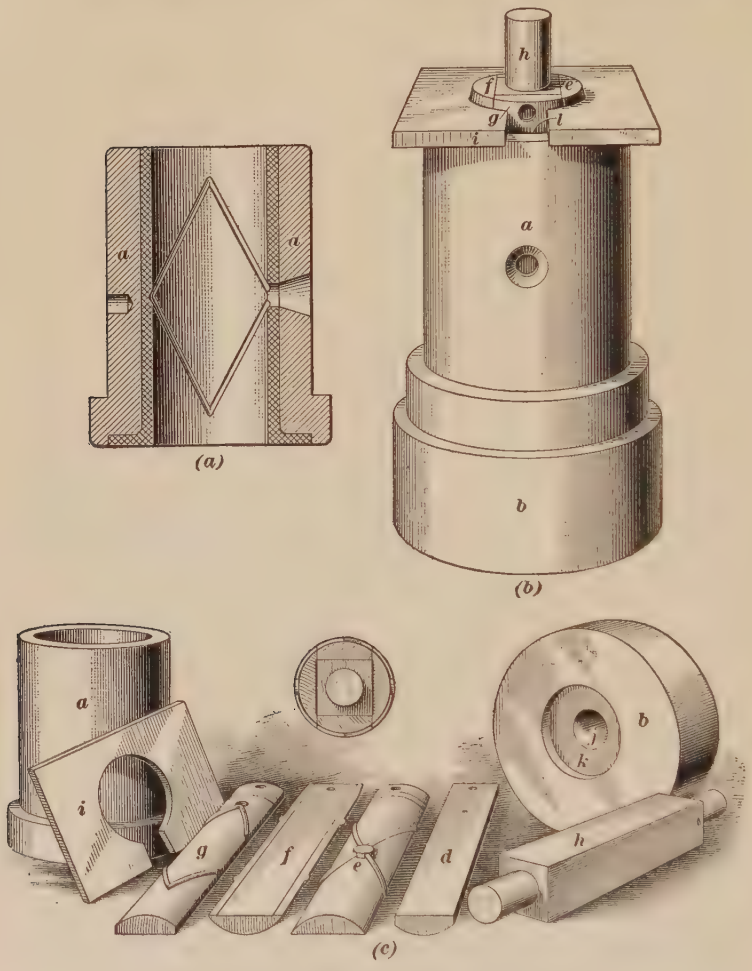

Fig. 17

set square across the plate *c* and bolted to it, and the engine frame *a* is set to a center line on the plate *c*. Standards *e* rest on the parallel *b* under each end of the engine shaft or man-

drel *f*. The bottoms of the standards *c* have projections *g* that fit in the grooves in the parallel *b*, and brackets *h* with vertical adjustment are bolted to the top of the standards. These brackets have V-shaped tops that support the shaft of

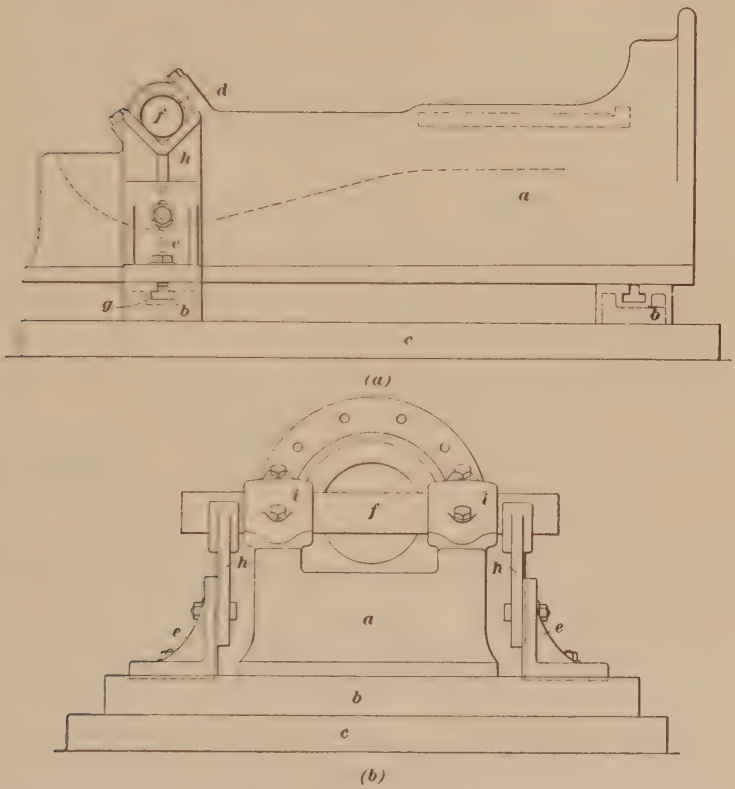

FIG. 18

the engine or a mandrel *f*; when the mandrel is properly adjusted, the Babbitt is poured in the two boxes *i*.

77. A more elaborate fixture for holding the mandrel, and one that is self-centering, is shown in Fig. 19. The lower guide bars on the engine bed *a* having been planed, a fixture shown at *b* is placed at each end of the engine guides and these support a bar *c* with a casting *d* on the end to hold the babbitting mandrel *e*.

Boxes of different sizes may be babbitted by having several mandrels all the same size in the center *d*, but of different diameter in the journals *f*. The center of the hole in *d* for holding the mandrel *e* can be bored, if desired, $\frac{1}{8}$ inch or so higher than the center of the hole for the bar *c*. This will allow for the spring of the bar *c* and also bring the center of the journals a little above the center line of the engine, so that the wear will be down toward the center line and not away from it. Keys may be fitted in the bar *c* and the castings *b* and *d*

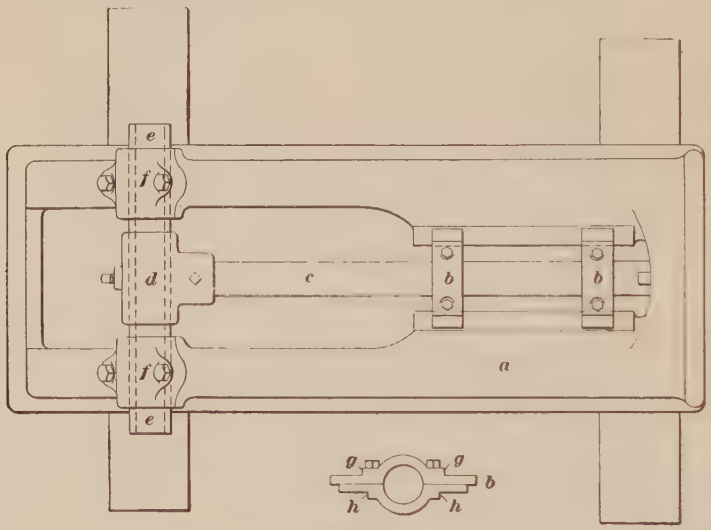

FIG. 19

to level the mandrel *e*, or the keys may be omitted and the mandrel *e* leveled by a surface gauge, or a spirit level may be used on the mandrel *e*. The rig shown in Fig. 19 can be made to serve for babbitting two sizes of engine by making the casting *b* with two sets of shoulders *g* and *h* to fit the guides of two sizes of engine.

78. Jig Method of Babbitting Pillow-Blocks of Engine.—When a large number of engines are to be built, a babbitting jig may be made for each size, as shown in Fig. 20, which is a single casting *a* with a rib *b* to stiffen it. The casting

is planed under the lugs *c* to fit the engine guides and bored at the end *d* so as to receive and support the babbitting mandrel. Many other forms of mandrels may be designed to meet the requirements of the case in hand.

79. Rebabbitting of Box.—In case a babbitted box is so worn down as to require renewal, first chip out the old Babbitt metal and then proceed to rebabbitt as nearly in the way described for a new box as the appliances at hand will permit.

80. Babbitting Journal Brasses.—Journal-box brasses are sometimes lined with Babbitt metal. It is necessary to *tin*—that is, wipe with Babbitt—the surfaces of the brass so that the Babbitt will adhere to it. In tinning a bearing, it is first

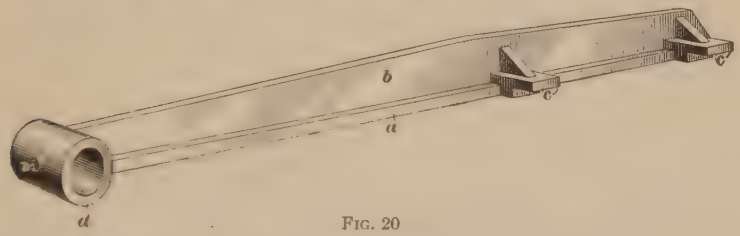

FIG. 20

heated as a precaution to drive off any moisture, after which every part not to be tinned is coated with a mixture of graphite and water of sufficient body to leave a coat of graphite upon drying. In case graphite is not available, a mud of fireclay and water may be similarly used with equally good results. When dried, the part of the casting to be tinned is cleaned of the graphite and well rubbed over with a swab dipped in a tinning solution. It is then immersed in the *tin pot*, containing a melted mixture, usually composed of approximately 42 parts tin and 58 parts lead, by weight, though these proportions are sometimes slightly varied. After the casting has reached a temperature sufficiently high to cause the metal to run readily over its surface, it is removed and immediately gone over again with the swab to insure that all parts are properly tinned. It is finally rubbed with a bunch of clean waste to smooth the surface, and the graphite is also brushed off. The

tinning solution is made by dissolving zinc in muriatic acid; sometimes sal ammoniac is added. Tinning salts are also on the market. After the surface is thoroughly tinned, the Babbitt is poured in the usual way; but in this case unites with the tinning and is held firmly to the brass.

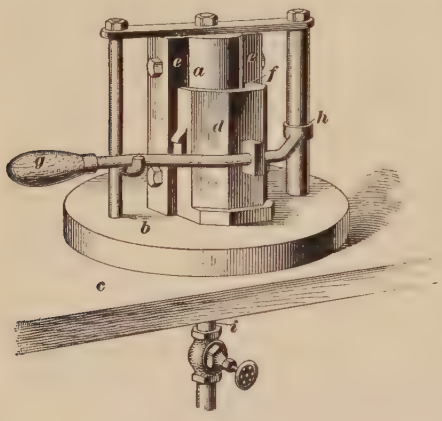

FIG. 21

81. A special mandrel for babbitting brasses is shown in Fig. 21. The mandrel consists of a hollow cast-iron cylinder *a* resting on a base *b* bolted to a table *c*. The cylinder *a* is turned to the proper diameter and the edges of the brasses *d* rest against two lugs *e* of the cylinder, leaving a space *f* between the mandrel and the surface of the brass that is to be filled with Babbitt. The brass *d* stands on the base *b* and is held against the lugs *e* of the mandrel *a* by means of a curved lever *g* hinged to the frame at *h*. The Babbitt is poured from a dipper into the space *f*, and the brass is removed as soon as the metal sets. The cast-iron mandrel *a* is cooled by means of a circulation of water that enters through a pipe *i* attached to the center at the bottom.

GENERAL APPLIANCES AND PROCESSES

(PART 2)

GENERAL SHOP PROCESSES—(Continued)

SOLDER AND SOLDERING

1. **Soldering** is the process of uniting metals by means of solder. **Solder** is an alloy of lead and tin or other metals, that melts at a comparatively low temperature. The solder is applied to the work in the molten state. It then adheres to the surfaces to be joined, provided they are properly prepared, and unites solidly with them while cooling. To assist the flow of the solder and to unite it with the metal, the surfaces to be joined must be covered with a *flux*, by which is meant a substance that promotes the fusing of metals.

Solder is usually composed of tin and lead, or tin, lead, and bismuth. It is cast in short blocks, or sticks that can be easily handled, and is sometimes made in the form of wire. The proportions of the metals used in making a solder will affect its hardness; the greater the proportion of lead employed, in general, the softer the solder will be.

2. Solders are sometimes classified as soft and hard solders, the term *soft solder* being applied to solders used when soldering, and *hard solder* to the spelter employed when brazing. In this Section soft solders are called *solders* and hard solders, *spelter*.

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Table I gives the proportions of the constituents of solder and the fluxes commonly used for various kinds of work. In interpreting the table, either tin 50 per cent. lead 50 per cent., or tin 64 per cent. and lead 36 per cent. may be used for copper, brass, or general work; and either chloride of zinc, resin, alcohol, or sal ammoniac may be employed as a flux, no matter which of the metals named are to be soldered or which percentage of lead and tin is used.

3. Preparing Solder.—Solder is usually bought ready for use, but occasionally it may be found necessary to make it.

TABLE I

PROPORTIONS OF CONSTITUENTS OF SOLDERS AND THEIR CORRESPONDING FLUXES

Metals to Be Soldered	Solders			Fluxes
	Tin Per Cent.	Lead Per Cent.	Bismuth Per Cent.	
Lead-wiped joints	50	50		Tallow
Galvanized iron or steel	50	50		Chloride of zinc or sal ammoniac
Tin plate or tinned iron	50	50		Chloride of zinc, or resin, or alcohol
	64	36		
Copper, brass, or general work	50	50		Chloride of zinc, resin, alcohol, or sal ammoniac
	64	36		
Iron or steel	50	50		Chloride of zinc
Pewter	20	40	40	Resin or olive oil

When preparing solder, the tin is first melted in a crucible, preferably of clay instead of iron, in order that no trace of the iron may enter, as its presence tends to harden the solder. The lead is then added in small quantities, the mixture being constantly stirred with a wooden stick until all the lead has been

put in and the solder has become thoroughly mixed. It is then poured into molds of any desired shape, usually of iron. Although lead has a higher melting point than tin, it oxidizes more readily when melted alone and for this reason the tin is

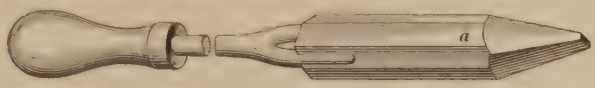


FIG. 1

melted first. If bismuth is also used, as is sometimes done to lower the melting point of a solder, it should be added last and in powdered form; and the solder should first be removed from the fire; otherwise, the bismuth will evaporate.

4. Equipment for Soldering.—A very simple equipment is required for ordinary soldering; it consists of a *copper bit* and a *fire-pot* in which to heat it. The copper bit, or *soldering iron*, Fig. 1, is a piece of copper *a* drawn to a point or edge and fastened to an iron rod having a wooden handle. The bits used for soldering must be of sufficient weight to hold the heat necessary to heat the metal and fuse the solder during a reasonable length of time. If they are too light, the soldering is apt to be very uneven in quality, and the bits will require such frequent reheating that they will be troublesome. If they are

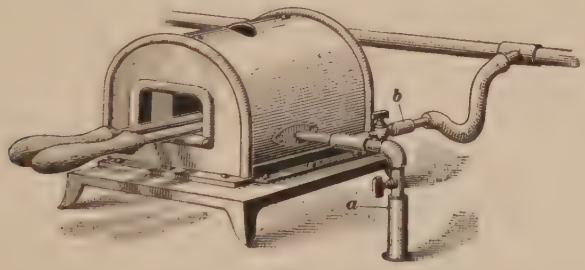


FIG. 2

too heavy, the work of handling them will be laborious, and the time required to reheat them will be excessive. An average weight of bit is 6 or 7 pounds.

5. The soldering iron may be heated in any kind of fire. In Fig. 2 is shown one type of gas furnace for this purpose.

The gas and air, which enter through the pipes *a* and *b*, must be so proportioned as to give a blue flame. A lack of air will cause the flame to burn yellow and soot the iron, while too much air will tend to reduce the flame and perhaps extinguish it entirely. Portable gasoline-fired torches and charcoal furnaces are also used for soldering, the latter more particularly by plumbers. When a soft-coal fire is used to heat the iron, the soldering iron should be protected from direct contact with the coal, by means of a thin sheet of iron laid between it and the coal. The iron need only be heated to such a temperature as will melt the solder.

6. Soldering Flux.—The least film of either oxide, grease, or dirt on the surface of the metal will usually prevent the adhesion of the solder; therefore, the surfaces to be joined must be thoroughly cleaned, or coated with some substance that will reduce the oxides to the metallic state or that will destroy the grease and deposit a thin film of tin on the surface to be soldered. For this purpose, a soldering fluid or some other kind of flux is used.

Of all the fluxes used, the *chloride-of-zinc soldering fluid* possesses the greatest range of usefulness. It is made by placing small clippings of zinc in hydrochloric, commonly known as muriatic, acid that has been diluted with an equal quantity of water. The acid vigorously attacks the zinc, causing bubbles of gas to rise and forming chloride of zinc. Zinc should be added until the bubbles cease to rise while a small amount of the undissolved metal remains in the liquid. When the acid has dissolved all the zinc with which it will unite, the liquid is strained and thinned by adding an equal quantity of water. A few small pieces of zinc are then placed in the liquid to neutralize any free acid that may remain.

7. The same flux cannot be used on all metals. Sal ammoniac is commonly used on copper or brass, chloride of zinc on iron, resin on tinned iron, and resin or tallow on lead. The soldering fluid, however, is the best all-around flux. By adding $\frac{1}{2}$ ounce of sal ammoniac to 4 ounces of the liquid, it can be

used in soldering iron or steel without first having to tin the surfaces to be joined.

Copper, brass, or iron not galvanized may be prepared to receive solder by cleaning the surfaces and applying the chloride-of-zinc soldering fluid. A stronger joint is assured by tinning the metal before soldering, in which case resin is the proper flux.

8. Tinning.—In copper-bit work, and also in blowpipe work, there is a preliminary operation known as *tinning*, in which the metals to be united are properly prepared for soldering. This operation consists in spreading a thin layer of solder on the surfaces of the metals and causing it to adhere and make a firm metallic union therewith. Its object is so to prepare the surfaces of the metals that they will readily unite with the melted solder that is applied to them in the process of soldering. All the common metals become tarnished when exposed to the air and this tarnished surface must be removed and the bare, clean, metal exposed to the influence of the solder; otherwise, the solder will not adhere to the metal. Great care should be taken to give the tinning a uniform thickness and have it free from imperfections. Small lumps or ridges of solder in the tinning coat must be carefully taken out, as they will interfere with the proper closing of joints and seams. Any superfluous solder can be shaken off or wiped off with clean waste or cloth.

9. Copper bits must be tinned before they can be used for soldering purposes. One method of doing this is to heat the bit until it melts solder, but not until it is red hot, then lay it on a brick or other suitable material, and file the flat sides at the point to a distance of about 1 inch, or as far back as it may be desirable to tin the bit. When thoroughly clean, rub the filed surfaces on a piece of solder over which some pulverized resin has been sprinkled. The hot copper will quickly melt the resin, which prevents the copper from tarnishing before the solder melts. The resin also facilitates the adhesion of the solder to the cleaned copper. If the bit is red hot, it will oxidize the instant that the file leaves it, and tinning cannot be done

with resin as a flux. Another way of tinning a bit that is to be used for soldering is to rub it, while hot, on a block of sal ammoniac having a few drops of solder spattered over its surface. The sal ammoniac reduces any oxide that may be present on the bit, and the solder adheres to the clean copper instantly on coming in contact with it.

Another quick way is to dip the point of the bit, while hot, in a saturated solution of sal ammoniac and water for an instant before rubbing it on the solder. But all four sides are tinned by this method and this is not always desirable.

When a bit is overheated, the coating of solder, or the tinning, as it is called, is reduced to a yellow powder and is destroyed. The bit must be tinned before it can again be used.

10. Making Soldered Joint.—In soldering, the parts to be joined are heated by a copper bit, by a blowpipe flame, or by some equivalent means, to the fusing point of the solder.

FIG. 3

Solder flows best at high temperatures, provided the temperature is not so high as to oxidize it, and will flow into a joint until it is chilled; therefore, it will flow farthest when it possesses a large excess of heat above that which is necessary to maintain it in the fluid condition. In soldering, bits that are barely hot enough to melt the solder should not be used, because the solder will unite only at the edges of the metal and will not flow into the joint properly.

The metal to be soldered may be heated by contact with the hot bit, and by moving the bit just fast enough to cause a little melted solder to follow the point. This body of solder increases the area of contact and conducts heat from the bit to the metal with great rapidity. In working with the blowpipe, the necessary heat is applied directly to the metal by the flame which must be so handled as to avoid overheating or oxidizing either the metal or the solder.

11. Examples of Soldering.—If two pieces of sheet brass, like those shown in Fig. 3, are to be soldered together, the surfaces to be soldered are first rubbed clean and a little of the

soldering fluid is applied with a small brush or a feather. The bit is then heated to the proper temperature, which can be determined by striking it a quick glancing blow with the hand. Any dirt is thus removed and a clean, tinned surface exposed. When hot enough, the molten tin on the bit has a streaked appearance when the hand is brushed over it. With a little experience, the proper temperature can be easily told by this method.

When the bit is properly heated, a drop of solder is melted from the stick with the point of the bit, allowed to fall on one of the fluxed surfaces, and spread over it with the hot bit, care being taken to get the surface well tinned. The other piece is then prepared in the same way, and both pieces are placed in position and pressed together with the hot bit. The heat from the bit heats the pieces of brass and melts the solder on the surfaces; the bit is then removed and the pieces are held together until the solder has become hard. The soldering fluid that still remains on the pieces must be washed off, so as not to corrode the brass.

The ability to make neat and fast joints is a matter of practice. The method of soldering is varied slightly to suit conditions, as, for instance, when two pieces are laid edge to edge, and the molten solder is drawn along by means of the hot copper bit.

Iron articles may be tinned by thoroughly cleaning the surfaces and treating them with chloride of zinc or sal ammoniac before the solder is applied.

12. Sometimes, as in seam soldering, the soldering iron is rubbed back and forth along the work, slowly advancing, the stick of solder being applied to the point of the iron from time to time. The heat from the iron melts the solder at once and it runs into the seam.

Where the soldering iron cannot be used, the work may be heated by means of a blow torch as shown in Fig. 4, in which *a* is the work, *b* the torch, and *c* the blast, or flame, from the torch. Small chips of solder are dropped on the pieces to be soldered before the blow torch is applied. When the solder has melted, it should be spread around by means of a small copper or iron

wire, the two pieces to be soldered being, of course, suitably held together during the soldering.

13. Soldering may also be accomplished with two ladles, one being filled with solder and held over the pieces to be soldered, the other being empty and held beneath. The upper ladle is then tilted and the solder caused to spill over the pieces into the lower ladle. The soldering of cables for electrical work thus is very effectively accomplished. The pouring of the solder back and forth through the strands of the cables removes all dirt most thoroughly, and should be continued until the solder has by cooling, become sufficiently thick to allow the joint to

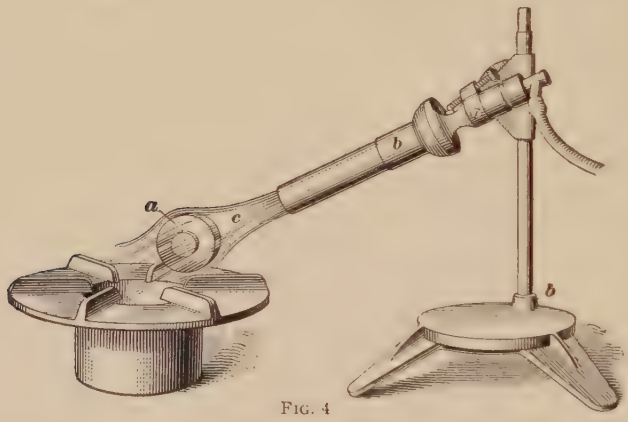


FIG. 4

be wiped. A pad for wiping may be made from a number of layers of heavy duck well soaked in tallow.

14. Another method of soldering applied largely to electric terminals and similar work consists in setting the terminals, which are of brass or copper, in line and directing a torch on several of them at once. When sufficiently heated, stick solder of small diameter is pressed into them and at once melts, filling the hole in each. The terminals, which may then be considered as small cups containing molten solder, are gripped in a pair of tongs, one at a time, and the end of the cable or wire to which each belongs is forced into the cup and thus held until the solder has cooled enough to solidify and hold the

terminal and the cable or wire together. The solder that is displaced when the cable or wire is pressed into position of course falls to the floor.

15. Soldering Aluminum.—All copper and tin alloys, and, in fact, most metals, have oxides that can readily be dissolved in some flux, thus leaving the surface of the metal clean, so that the solder may adhere to it. The oxide of aluminum, however, is not soluble in any known flux; hence, the surface must be covered with the melted solder and the oxide rubbed off with the point of the copper bit. In this case, the bit need not be tinned, but should be rather heavy, so that it will hold a large amount of heat. A good solder for aluminum has the following composition:

	Parts
Aluminum	1
Phosphor tin	1
Zinc	11
Tin	29

16. In making the solder, the aluminum should be melted first; the zinc should then be added in small pieces, taking care not to solidify the melted aluminum; the tin should then be added in the same way; and last of all, the phosphor tin, and the mixture thoroughly stirred with a brass rod. This solder should be made in a graphite crucible. The reason for melting the metals in the order given is that, if the metals with the lower melting point were heated to the melting point of aluminum, they would be partly vaporized, thus destroying the proper proportion of the alloy. To solder aluminum, the bit is heated to a red heat, some solder is placed on one of the surfaces to be united, melted with the copper bit, and then the aluminum oxide rubbed from the surface beneath the molten solder until the solder adheres evenly to the entire surface. The surface of the other piece is then treated in the same way, the two pieces placed together, and heated with the copper bit or with a torch until they unite.

17. Sweating.—Sweating is a process of soldering metals without using a copper bit, the surfaces to be joined being

cleaned and tinned with solder and then brought together and heated until the solder flows and unites the pieces, which may be pressed together while cooling. The process of *sweating on*, as it is usually called, is frequently adopted for temporarily holding in place pieces of work to be turned or otherwise finished to shape, after which the parts may easily be separated by heating and melting the solder that holds them together.

18. In boring out boxes for bearings, the pieces are sometimes sweated together and then bored and finished. After this they are again heated, in order to melt the solder, and the pieces taken apart. When brass boxes *b*, Fig. 5, are sweated together, liners *a* are sometimes placed between them to allow for wear when in service. The faces of the brasses and the liners are planed smooth and rubbed bright. They are then heated in the forge, and, when hot, the brasses are fluxed with sal ammoniac or cleaned with acid, and tinned by the method employed in tinning the copper bit. The liners, if of iron, are fluxed with borax and tinned. The pieces are then put together and heated so as to melt the solder. If too light to make a tight joint, they are weighted down until cold. After being bored out and finished in the machine shop, they are melted apart and the liners taken out.

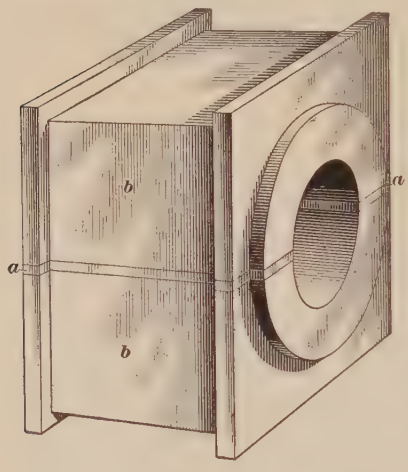


FIG. 5

SPELTER AND BRAZING

19. **Brazing** is a process for joining two or more metals by means of **spelter**, whose temperature of fusion is much higher than that of solders, and whose strength is greater. Spelters are composed of copper, zinc, tin, silver, etc. in proportions that are varied to suit the requirements. A good soft spelter is made with 1 part of copper and 1 part of zinc; 65 parts of copper and 35 parts of zinc make a good spelter for general work; 13 parts of copper, 5 parts of zinc, and 82 parts of silver make a good spelter for soldering band saws. Coin silver is sometimes used as a brazing solder.

20. Only such metals as iron, copper, and brass, whose temperature of fusion exceeds that of spelters, can be brazed. In brazing, the temperature required to fuse the spelter is so high that soldering bits cannot be used.

In preparing the spelter, the metals used are fused together, then filed to a powder, and sometimes made into a paste by the addition of calcined borax and water.

The proportions of copper and zinc in the alloy vary greatly, depending on whether a hard or a soft joint is desired. If a very hard and tough joint is wanted, the proportions may be as much as 3 parts copper to 1 part zinc; while if a soft joint is wanted, the zinc may exceed the copper. Occasionally the brazing material may consist simply of copper filings or copper ribbon; again, other metals, especially silver, may enter into the brazing alloy with copper and zinc.

21. **Preparing Spelter.**—When used in granular form, spelters may be readily made simply by melting the several constituent parts together, then filing into fairly coarse grains and mixing with the flux. Sometimes, just before using, the mixture is made into a paste by the addition of water.

Brass wire or rod may be used in place of the granular form of spelter. The wire or rod should be dipped into boracic acid or covered with a paste of borax and water, then applied to the joint and held there until it commences to melt, when it should be moved slowly along the joint.

22. Table II gives the proportions of the constituents of spelters and their corresponding fluxes, as commonly used for various kinds of work.

23. Brazing Equipment.—The heat is usually applied to the parts to be brazed, by means of an intensely hot blowpipe flame. Large work, having a considerable weight of metal, may be heated in a forge fire. For brazing collars,

TABLE II

PROPORTIONS OF CONSTITUENTS OF SPELTERS AND THEIR CORRESPONDING FLUXES

Metals to Be Brazed	Spelters				Fluxes
	Copper Per Cent.	Zinc Per Cent.	Silver Per Cent.	Tin Per Cent.	
Wrought iron, steel, and general work	64	36			Borax, sal ammoniac, or mixture of borax and sal ammoniac
Cast iron	55	45			Cuprous oxide
Brass tubing	17	33	50		Borax
Steel band saws	13	5	82		Borax
Copper	50	50			Borax
	55	40		5	
Brass, soft	22	78			Borax
Brass, hard	45	55			Borax

etc. on 2- or 3-inch tubing, the fire is arched over with coke, thus making a hot chamber in which the work may be heated uniformly. A gasoline torch may be used on small work to good advantage.

In Fig. 6 is shown a very convenient form of *blowpipe* to be used in connection with a bellows. The blowpipe consists of a gas pipe *a* having a controlling cock attached; an air or blast

pipe *b*, also having a controlling cock attached; and an iron pipe nozzle *c* joined by a special casting to the pipes *a* and *b*.

24. Fig. 7 shows a form of *brazing table*, or forge, operated by gas and air. It is provided with two blowpipes *a*, which are

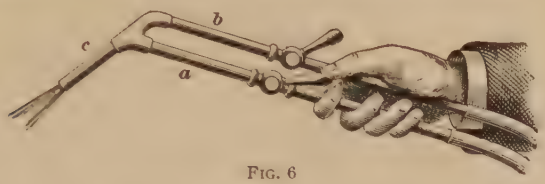


FIG. 6

adjustable in any direction. The top *b* of the table, or forge, consists of a fireclay slab on which are placed any suitable number of bricks *c* so that the work may be properly supported

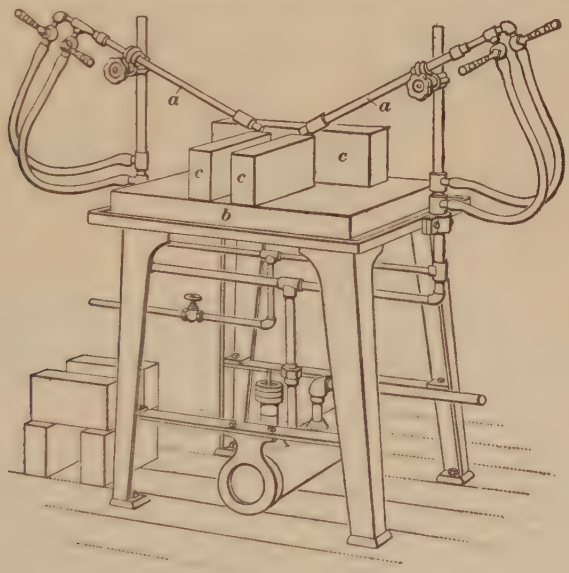


FIG. 7

or enclosed. The flame when properly adjusted should be of a blue color; if there is too little air, it will be yellow, while too much air will be indicated by a short flame accompanied by noise and a tendency to be blown out.

25. In Fig. 8 is shown a form of *blower* suitable for supplying air to the blowpipe. It consists of a single-acting bellows having an air inlet check-valve on the inside of the bottom board *a*, and another on the upper side of the pressure board *b* and within the rubber storage bag *c*, which is enclosed by a cord network to prevent it from bursting.

The bellows is operated as follows: The top board, which is hinged at the lower end and supported by a spring within the bellows, on being pushed down with the foot compresses the air within the bellows and forces a portion of it through the upper check-valve into the rubber bag. When the pressure of the foot is removed from the pressure board, the bellows will again be filled with air by the spring, which raises the pressure board. This operation is continued, thus filling the rubber bag with compressed air, which flows to the blowpipe through the rubber tube *d* when the air cock of the blowpipe is open. The elasticity of the rubber bag serves to equalize the pressure of the blast. This form of blower is capable of furnishing a strong and nearly continuous blast through a jet $\frac{1}{4}$ inch in diameter.

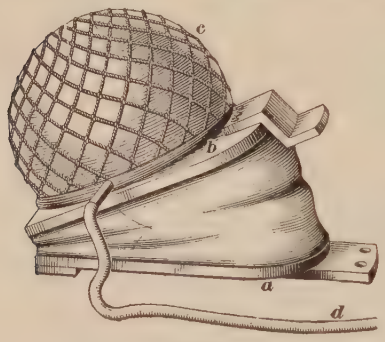


FIG. 8

26. The blowpipe should be connected by rubber tubing to a gas burner or other supply and to the blower. The bore of the tubing should be large enough to avoid excessive friction.

Air is mixed with the gas before it is consumed, as otherwise the flame is low in temperature and gives off products of combustion that not only tarnish the metal, but also cover it with a coating that keeps the flame from coming in contact with it. The gas should be turned on first and should be lighted at the jet; air is then admitted gradually until the flame is brought to the proper size and color. If too much gas is admitted, the flame will be yellow and will blacken the work by

depositing a film of carbon on it. If too much air is admitted, the flame will be short, ragged, and noisy, and the temperature will be too low to heat the metal properly. The flame is hottest and at its best condition when it burns with a pale-blue or bluish-green color, with no white or yellow parts.

27. Brazing Flux.—The flux for brazing is almost always borax, though a mixture of 10 parts by volume of borax and 1 part of sal ammoniac is sometimes employed when brazing wrought iron or steel. In using borax, it should be fused to a

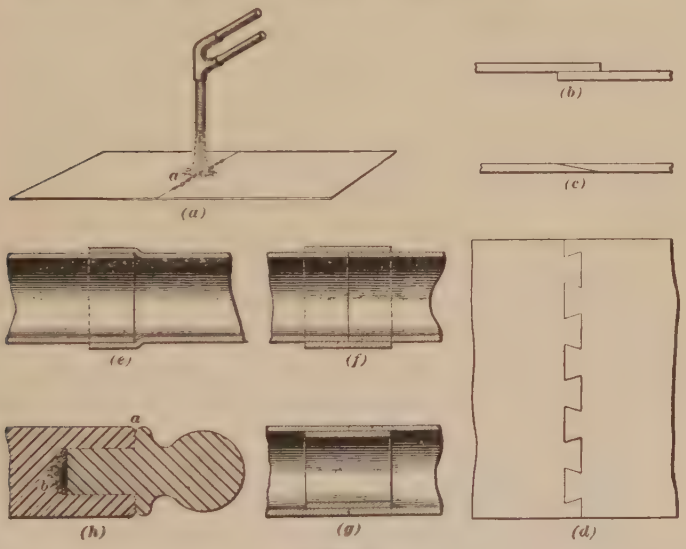


FIG. 9

solid mass, thus driving off the water it contains, after which it should be again pulverized. Treated thus, it is known as *calcined borax*. As a substitute for borax, ground glass may be used. The purpose of the flux is to prevent oxidation of the metals while in a heated condition.

28. Types of Brazed Joints.—In Fig. 9 are shown a number of joints, suitable for different classes of work. The joint shown in (*a*) is called a **butt joint**; the lumps of spelter at *a* are placed in position ready for fusion. The strength of

this joint is slight, depending on the area of the surfaces that are united by the spelter. The strength is greatly increased by lapping the plates, as in (*b*). An equal amount of strength may be secured and the appearance greatly improved by beveling, or splaying, the edges, as in (*c*), provided that the plates are thick enough to permit the beveling to be extended to a sufficient width. The strongest joint for sheet metals is made by dovetailing the edges together before brazing, as in (*d*).

Thin tubing may be joined by a **slip joint,** as shown in Fig. 9 (*e*), by first annealing one of the ends and forming it into a socket. The end is flared out by means of a drift pin or plug, care being taken not to split the pipe, after which the metal is expanded by hammering until the other end will enter properly.

Circular butt joints may be strengthened by means of a band put on externally, as in Fig. 9 (*f*); or by an internal ferrule, as in (*g*).

29. Making a Brazed Joint.—The surfaces of the metals to be united are first thoroughly cleaned, after which the spelter, generally in granular form, is mixed with a flux and placed on the metals to be brazed and which have been previously brought in contact. Heat is then applied, causing the spelter to melt and flow between the abutting surfaces. Upon cooling, a solid mass is obtained.

The metals to be brazed should, as already stated, be thoroughly cleaned and brightened either by filing, grinding, scraping, or rubbing with emery paper. They should next be nicely fitted, scarfed if necessary, clamped, riveted, tied with iron wire, or forced together, and then placed in position and covered with the spelter that has been mixed with the flux, usually wet with water.

30. The metals, after being placed in position upon the brazing table or forge, should be brought slowly to such a temperature as will melt the spelter, and kept at this temperature until the spelter has penetrated the entire space between the surfaces. The joined metals should then be allowed to cool slowly to avoid warping or possible cracks. As little space as

possible should be left between the surfaces of the uniting metals, for the less alloy permitted, the stronger will be the union. Equally important is slow and uniform heating; if the heating be too fast or too high, burning, as well as unequal heating, is liable to occur, resulting in an imperfect union. An iron wire or rod of small diameter and suitable length will be found most convenient to assist the alloy in finding its way into the space between the metals. A long-handled iron spoon should likewise be available to add more spelter or flux if more of either is needed.

If the pieces are small and easily handled they may be manipulated during the brazing process by means of a pair of tongs to assist the spelter, after it has melted, to flow in the desired direction.

31. Sometimes the spelter is used as a very thin ribbon, which is placed between the surfaces to be brazed. These surfaces are then tied, riveted, or otherwise held together and heat is applied. In brazing brass tubing, for example, the abutting ends are tapered and reamed respectively, so as to telescope into each other, being separated by a thin ribbon of silver alloy. This process has been found to give excellent results. Certain kinds of brass tubing have a tendency to open at the seam when being brazed, but this danger is practically eliminated by the use of silver alloy.

32. Brazing a Knob to a Rod.—A knob brazed to the end of a rod is shown in Fig. 9 (*h*). To do this job properly, the spelter must flow into the socket and secure the shank of the knob. A good joint cannot be made by merely securing the edges at *a*. The rod should be held vertically in a suitable fire or flame until both the socket and the knob are well heated. Borax and spelter are then placed in the socket, and as soon as the spelter is melted, the shank of the knob should be inserted and pressed into place. The spelter will flow outwards as it is displaced by the shank, filling the entire joint; or the space *b* at the end of the shank may be filled with spelter, as shown, and the knob inserted. If the knob and socket are then heated in an inverted position, the

spelter in *b* will flow around the shank and sweat down to the rim *a*.

33. Brazing the Joint of a Pair of Tweezers.—The brazing of a pair of tweezers, shown in Fig. 10, is a good example of flat brazing. The surfaces to be brazed are cleaned; then some of the spelter is applied to each surface, and the pieces are tied together with a fine iron wire and heated sufficiently to melt the spelter. The heat may be applied with a blowpipe or by holding the pieces in a pair of hot tongs. When the spelter is melted, the piece is cooled and the iron wire is removed. The wire may be omitted when hot tongs are used, the pieces being placed in their proper position and held there by the tongs.

34. Brazing Tempered-Steel Articles.—A tempered-steel article should be heated carefully in brazing, so as to draw the temper as little as possible. The selection of the proper

FIG. 10

spelter is important. If an article tempered to a dark-blue color is to be brazed without spoiling the temper, a spelter that will melt below 600° F. must be used. As this spelter is weaker than the harder kinds, the brazed surfaces must be larger, so as to make the joint equally strong.

When brazing steel articles that are to be tempered, the pieces are sometimes held together by snapping a small metal clip over the joint. This clip is left on after the brazing is completed and while the piece is being tempered, provided the tempering is done after the brazing. By this means, the pieces may be brazed with spelter or silver, and subsequently tempered, the clip or clamp being removed after the work is finished.

35. Butt Brazing.—If two thin pieces are to be butt-brazed—that is, brazed end to end, as in making a butt weld—the pieces must be held in position in a bench vise, hand vise,

or clamp, and the heat applied with a pair of tongs or with a blowpipe. The surfaces to be brazed are fluxed with borax and then clamped in position, and a little spelter is sprinkled on the side over the joint. The heat is then applied by means of a blowpipe, a Bunsen burner, or a hot iron, until the pieces are hot enough to melt the spelter, which will then flow into the joint. By giving one of the pieces a slight tap on the end, the pieces are brought tightly together. They are then allowed to cool and the remaining spelter is scraped off.

36. Lap Brazing.—Band saws are always lap-brazed, the two ends being filed to make an accurate joint. Silver solder is generally used, being applied between the two surfaces; or the surfaces may be coated with borax and the solder allowed to flow into the joint. Fig. 11 shows the two ends of a band saw filed for brazing. The pieces are clamped together

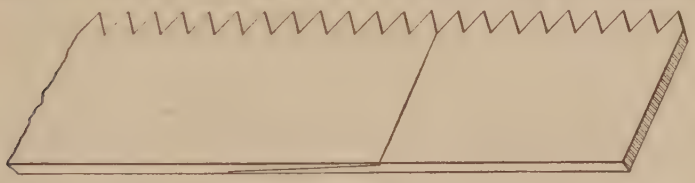


FIG. 11

or tied with a wire after having been fluxed. The spelter is either laid over the joint, or put between the pieces. When heat is applied, the spelter melts, and the pieces must be squeezed tightly together. An alloy containing 90 per cent. of silver and 10 per cent. of copper makes a good spelter.

37. Brazing Cast Iron.—The carbon contained in cast iron prevents most metals from adhering to it. The surface to be brazed should therefore be first coated with a metallic oxide—usually oxide of copper—made into the consistency of varnish and applied with a brush. The metallic oxide when heated acts as a reducer of the carbon on the surface of the cast iron to be brazed and really decarbonizes the surface of the metal for a short distance below it. The removal of the carbon leaves the surface of the metal with an open structure, since the spaces that formerly contained carbon are left empty.

The surface of the metal to be brazed is next brought to a red heat by means of gas torches or blast lamps. The oxide of copper is reduced to metallic copper and unites with the metal at the surface of the break. After the metal is brought to the required temperature, about 1,800° F., ordinary brass filings are put into the fracture and melted, as in the ordinary brazing process. The fact that the carbon is extracted from the iron for a short distance below the surface allows the brazing material to secure a firm grip on the surface of the metal, and results in very strong brazed joints. A brazing spelter as strong as cast iron or stronger than it is usually employed; hence, the joint is as strong as the original casting. The only difficulty with this brazing process is that the heating of the iron expands it permanently; hence, in some cases, finished machine parts so united must afterwards be brought to the proper size.

38. Brazing Broken Castings.—Commonly, a broken iron casting is consigned to the scrap heap; but this loss in many cases may be prevented by brazing the broken parts together. A coating of copper oxide is spread evenly over the fractured surfaces. The surfaces are then placed together properly, and brought to a cherry-red heat, which melts the flux. Spelter or brazing material is added, after which the piece is allowed to cool in the air. This method is used in cases where the castings are not subjected to extraordinary strains and are not excessively large. Castings should, however, be neither repaired in this way nor in any other when the repairing will cost more than would a new casting.

GAS WELDING

39. Oxygen-acetylene welding, commonly called *oxyacetylene welding*, is a process of uniting two metals by means of an oxyacetylene flame; that is, a flame produced by the burning of a mixture of oxygen and acetylene gases. When united by this process, metals are fused together without pressure, being allowed to flow together when in the molten state. A *welding stick* of the same material as the metals being welded is used to

supply the necessary metal to flow into the open spaces, the torch being directed on the end of this stick as well as on the parts to be joined. Both the oxygen and acetylene gases may be bought compressed in steel bottles or cylinders, ready for use, or they may be generated by the user. Because of the difficulty of manufacturing oxygen and the ease of preparing acetylene, oxygen is usually bought compressed to about 1,800 pounds per square inch, and acetylene is generated in the home plant. When the welding cannot all be done in one central place, the compressed form of acetylene, though more expensive, is much to be preferred. Portable outfits that generate the acetylene are also used.

40. Oxyacetylene Welding Apparatus.—The apparatus for oxyacetylene welding consists of a blowpipe or a blow torch and generators for producing the two gases, acetylene and oxygen, though it is the more common practice to use compressed oxygen instead. In Fig. 12 (*a*) is shown the apparatus for generating the acetylene gas, which is carried to the place where it is used by the pipe *a*. This apparatus is usually kept in a separate room. In (*b*) is illustrated a welding table *b*, the torch *c*, a hose *d* connecting the torch to the oxygen bottle *e*, a hose *f* connecting the torch to the back-pressure valve *g*, which is connected to the pipe *a* leading from the acetylene generator.

In Fig. 12 (*c*) is shown a portable oxyacetylene welding outfit. In this case, both the oxygen and the acetylene are compressed in steel bottles, the oxygen being stored in *h* and the acetylene in *i*. As the apparatus is mounted on a truck, it may be readily moved from one part of the shop to another.

41. In operating a welding set, the pressure of the oxygen is varied from 9 to 30 pounds, the acetylene from a few ounces to several pounds, depending on the class of work being done. An exterior view (*a*) and an interior view (*b*) of one style of torch are shown in Fig. 13. The capacity of a torch is measured by the size of orifice in the nozzle. Each torch is equipped with a set of tips *j*, Fig. 12 (*c*), which may be so fitted to the nozzle that the same torch is made available both for large and for

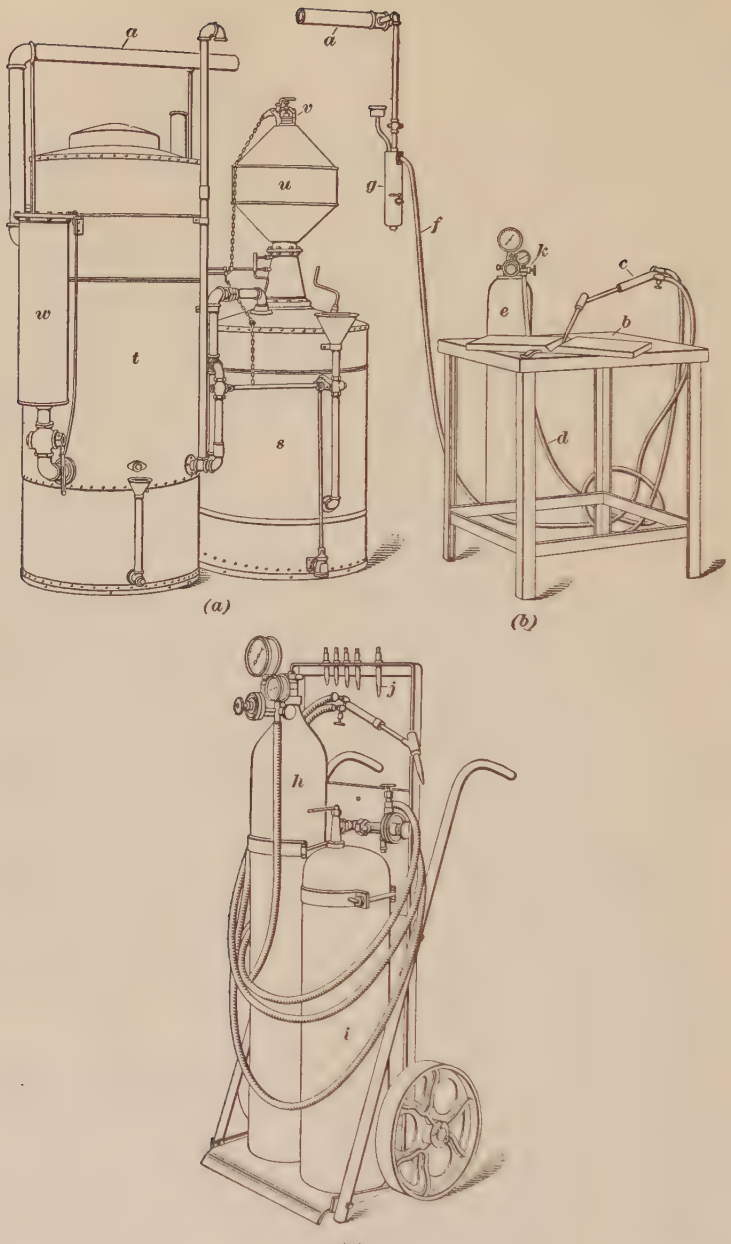


FIG. 12

small work. Referring to Fig. 12 (*b*), the oxygen flows from its bottle *e* through a regulating valve *k*, where it is reduced to the proper pressure, and from there to the mixing chamber *l*, Fig. 13 (*b*), in the head of the torch. The acetylene similarly flows from its source through a back-pressure valve *g*, Fig. 12 (*b*), and into the mixing chamber *l*, Fig. 13 (*b*), of the torch, where it thoroughly mixes with the oxygen, after which the mixed gases flow through the nozzle *m* and are ignited at the tip *n*. While oxygen is a non-combustible gas, though a supporter of combustion, acetylene is combustible, and there is a considerable tendency for the flame to travel back through the hose to the source of supply. However, the acetylene pipe in the torch itself is made as small and as long as practicable, thus tending to smother any flare back through the pipe. The velocity of the oxygen gas is also made very high, approximating 500 feet per second, and as the velocity of the explosion wave of acetylene is but 300 feet per second, the tendency for the flame to travel back is effectually guarded against. Additional precautions must still be taken to prevent air and oxygen from working back into the acetylene supply when the apparatus is not in use or if the nozzle of the torch should become clogged by a particle of molten metal, as sometimes happens.

42. The back-pressure valve *g*, Fig. 12 (*b*), is used to prevent air and oxygen from working back into the acetylene. A sectional view of this valve is shown in Fig. 13 (*c*). The flow of the acetylene through this valve is, under normal conditions, as indicated by the arrows; but if either of the two abnormal conditions just mentioned occurs at any time, either air or oxygen might flow back and produce an explosive mixture that would require but a spark to ignite it. However, the water *o* with which the valve is filled as shown, prevents such an outcome. Any back pressure forcing its way through the cock *p* would increase the pressure in the valve, thus driving some water up the central tube *q* and maintain a seal in the acetylene supply pipe, while a considerable increase in back pressure would increase this central column of water, and drive it entirely out of the pipe *r*. The oxygen would then blow off into the air.

43. Preparation of Acetylene.—As stated, the prevailing custom is to make the acetylene gas as needed, instead of using the compressed form. In order to explain clearly the principles involved in oxy-acetylene welding, a brief statement will be given of the theory of the formation and subsequent combustion of acetylene gas. Lime and coke, when intimately mixed and fused in the electric furnace, produce calcium carbide, a dark blue-gray slag, or stone, that is easily broken into lumps of various sizes as desired. When kept dry and away from air, it remains inactive; but when exposed to moisture it gradually slakes, giving off acetylene, a gas with a peculiar, onion-like odor. While the gas is not poisonous when inhaled in small quantities, it is exceedingly dangerous if mixed with air in a confined space, as any flame

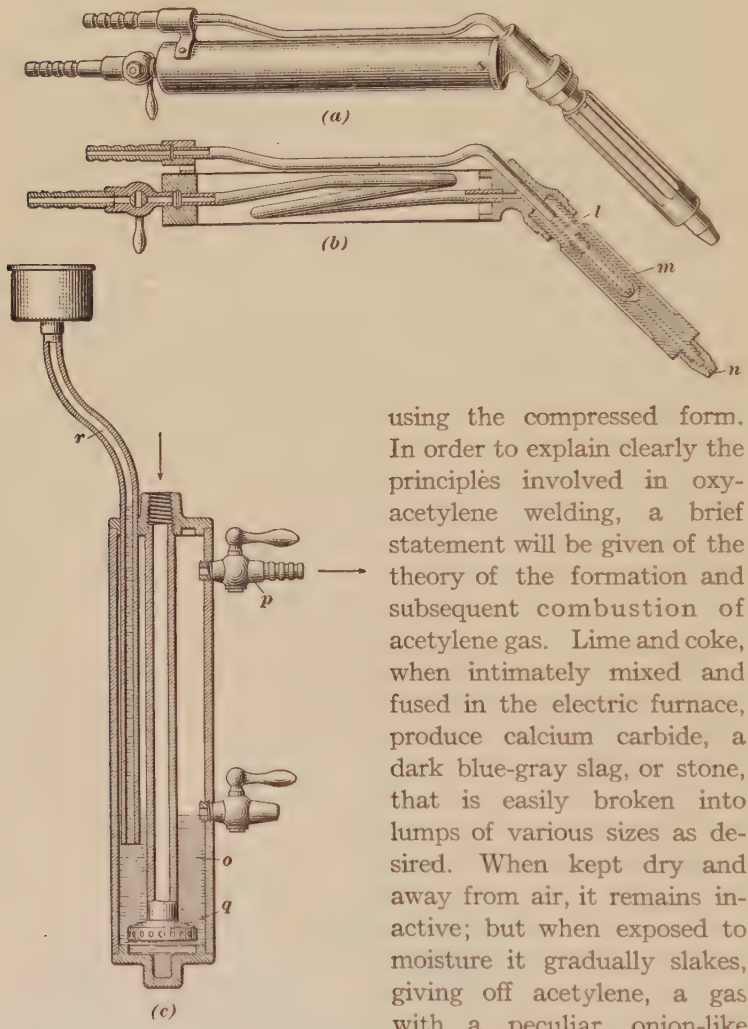


FIG. 13

brought near it is likely to produce a heavy explosion. To produce acetylene gas from calcium carbide, therefore, water should be brought into contact with it. When this is done, the resulting by-product is slaked lime. About $4\frac{1}{2}$ cubic feet of acetylene gas is obtained from 1 pound of calcium carbide.

44. Generators for the manufacture of acetylene gas are of two types, built respectively on the carbide-to-water or water-to-carbide principle. In the former, or carbide-feed type, the carbide is dropped into the water; in the latter, or water-feed type, the water is dropped on the carbide. The carbide-feed type is the more widely used, as it has closer pressure regulation. The generator shown in Fig. 12 (*a*) will be seen to consist of two main parts, the tank *s* being the generator, and the tank *t* the reservoir, or gas holder. On top of the generator tank is located a hopper *u*, which is filled with carbide from time to time and which is fitted with a controlling mechanism *v* operated by the reservoir.

This mechanism permits the carbide, a few lumps at a time, to feed down into the water in the tank, thus resulting in the formation of acetylene gas. The reservoir is of the ordinary gas-storage type, consisting of a hollow cylinder open at the top that holds the water, and a hollow cylinder open at the bottom in which the gas gathers. The gas passes over into the water and up into the inner cylinder, causing it to rise gradually as the pressure increases. The rise in pressure in turn shuts off the feeding of the carbide until such time as enough gas has been withdrawn from the reservoir to reduce the pressure, thereby causing the inner cylinder to sink gradually and to commence again the feeding of the carbide. The acetylene gas as it leaves the reservoir passes through a small tank *w* filled with felt, which serves as a filter.

45. In generators of the water-feed type, the carbide is placed in trays arranged in tiers or rows and the water is caused to flood them gradually as required.

With the formation of acetylene gas, heat is given off. If the rise in temperature is excessive, there is not only a decrease in the quantity of acetylene gas produced, but there are also

formed certain tar products, which tend to clog the apparatus and otherwise interfere with its proper working.

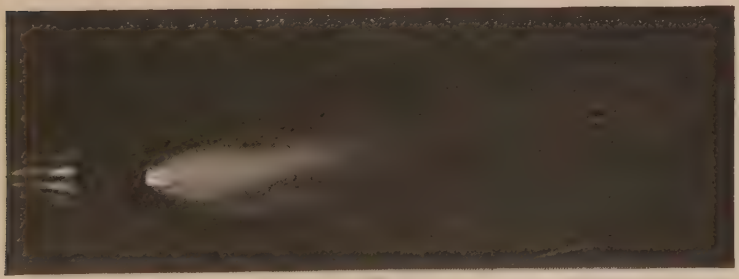
46. Dissolved Acetylene.—When acetylene in its compressed form is to be used, certain precautions must be taken, because when compressed to a pressure of more than 30 pounds, acetylene gas is liable to explode simply by concussion. In order, therefore, to make it commercially serviceable, it is dissolved in acetone, which is a constituent of wood alcohol and which has the remarkable property of absorbing at ordinary temperatures, about twenty-five times its own volume for every increase in pressure of 15 pounds. The volume of the acetone at the same time increases with the absorption of acetylene, being approximately one and one-half times greater at 180 pounds than at 15 pounds or atmospheric pressure. Accordingly, the acetylene is compressed into the acetone at a pressure of 150 to 180 pounds, and is then known as *dissolved acetylene*. It is, however, not yet ready to be used. If a steel bottle were to be filled with this liquid at the pressure indicated and placed in service, the pressure would, of course, gradually decrease as the gas was used and the volume of the liquid would likewise be reduced, although no liquid had actually been taken from the bottle. An ever-increasing space would thus be left in the bottle into which the gas contained in the liquid would expand, thereby forming a pocket of gas liable to explode by concussion. The acetylene bottle must therefore be filled with a porous cement made of charcoal or asbestos. This cement must be so arranged in the bottle that no shrinkage of this packing can occur. While acetylene gas made under such conditions costs more than when produced by and used directly from a generator, it has a compensating feature, extremely valuable at times, in that it has a freezing point of −49° F. It can therefore be used where the generator cannot; in fact, all generators must be kept at temperatures above 32° F., to prevent the water from freezing.

47. Preparation of Oxygen.—Owing to the great difficulty in the manufacture of oxygen, it is customary to purchase the compressed form. However, the place where it is to be used may be so remote from its place of production, and

(*a*)

(*b*)

(*c*)



(*d*)

FIG. 14

the cost of transportation so high, as to compel its manufacture by the consumer. There are several ways of making oxygen by chemical processes, though but one will be considered here; namely, a so-called *dry process*, in which chlorate of potash is mixed with manganese dioxide and burned in a furnace. The manganese dioxide apparently undergoes no change in this process, but its presence is necessary.

48. The apparatus for making oxygen by this process consists of a tank or furnace in which the oxygen is generated, a scrubber through which it is passed to cleanse it of impurities, a storage reservoir, and a compressor. A mixture of crystallized chlorate of potash and manganese dioxide in the proportion of about eight to one, is placed in the furnace and heat applied, usually from the outside. The generation of the oxygen commences at once, and the oxygen immediately passes into the scrubber, which is a steel tank containing pebbles or pumice stone and which has been further filled with a solution of caustic soda. The oxygen gas bubbling through the scrubber is freed of its impurities and then passes into the storage tank. From here it is drawn by the compressor and pumped into suitable steel bottles at any desired pressure.

As oil forms an explosive compound when brought in contact with oxygen, it must not be employed as a lubricant on the compressor or gauges, castile-soap water being used instead.

49. Flame of Torch.—When the torch is to be operated, the acetylene is first turned on and ignited, then the oxygen, both gases being regulated as may prove necessary. Acetylene burned alone in air gives a flaring brilliant white light, as shown in Fig. 14 (*a*), accompanied by heavy soot. With the two gases properly proportioned a small, very intense blue cone of flame with a temperature approximating 6,000° F. is produced at the tip of the nozzle, as shown in (*b*). This flame is surrounded by a semiluminous pink flame. An excess of acetylene results in a double cone, the larger being the less distinct of the two as shown in (*c*). With oxygen in excess the cone is very short, as illustrated by (*d*). Too much acetylene causes the metal about the weld to carbonize, while too much oxygen results in

oxidizing the metal, giving it also a rather spongy appearance. As a rule, therefore, the flame should be a neutral one, leaning, if at all, to an excess of acetylene.

50. Making Welded Joint.—In oxyacetylene welding, the necessity for absolute cleanliness cannot be too strongly emphasized, not only with respect to the surfaces of the metals to be welded and to the torch, but also with regard to the gas-generating apparatus and the chemicals used. Failure to secure good welds may sometimes be due to lack of appreciation of this fact.

In Fig. 15, a variety of ways of making joints are shown. The parts are placed in position and welded, the joints being

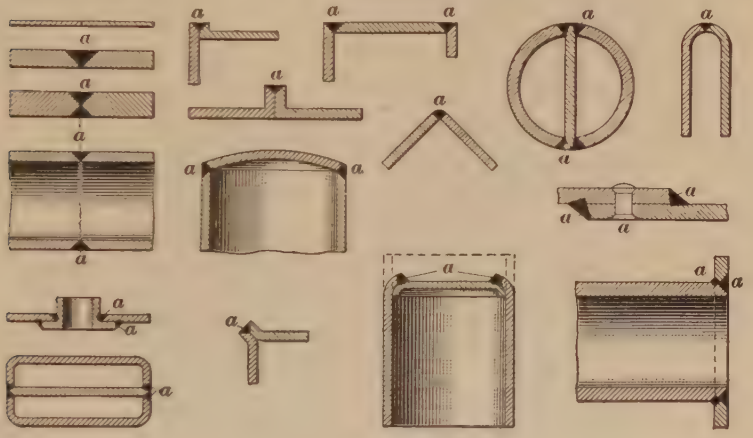


FIG. 15

made at the points *a*. The making of an oxyacetylene-welded joint is illustrated in Fig. 16. No protection is needed for the operator other than a pair of heavily smoked glasses. The torch *a* is held in one hand and the welding stick *b* in the other. The two almost touch within about $\frac{1}{32}$ to $\frac{1}{4}$ inch of the metal being welded. As the metal melts both the torch and the welding stick are, in the case of seam welding, moved along the seam, always retaining their relative positions. Added strength is sometimes secured by piling up the metal at the weld. A closer grain and toughness may be imparted by hammering the

weld while it is still red hot. Annealing is also beneficial, though not at all necessary for the usual run of work.

When repairing cracks, it is very essential to chip, machine, or melt away the metal around the edges before commencing the weld. When welding hollow work, it should be packed with dry molding sand to hold the metal in its softened condition, as well as to decrease any tendency toward warping.

51. Both sheet iron and steel are readily welded. All sheet-metal work is butt-welded, and when the thickness of the

FIG. 16

sheet exceeds $\frac{3}{16}$ inch the edges should be beveled on one or both sides, as shown in Fig. 17 (*a*) and (*b*), either by machine or by means of the torch. If this is not done, an imperfect weld will result, being more or less superficial and not extending the full depth of the metal. When the sheets are of appreciable thickness, they must be spread apart at one end, as seen in (*c*), and held thus rather loosely. If not spread apart, the plates will overlap as the welding progresses.

Wrought iron and steel present no difficulty in welding unless it be owing to some special shape or section.

Cast and malleable iron are rather difficult to weld. When welding these materials, the metal is frequently preheated and while in this condition the weld is made. Subsequent cooling should be done slowly, so that shrinkage strains and cracks may be avoided.

Brass is exceedingly difficult to weld because of its zinc component, which vaporizes at a low temperature. The metal should be carefully supported so as to retain its shape and the flame should be applied intermittently.

52. Strength of Joints Welded by Oxyacetylene. Good welding should result in the metal at the joint being about 80 per cent. as strong as the original stock. The gas-welding process is best adapted to light work or work requiring a fine

FIG. 17

appearance or great strength, in all of which features it excels the electric-welding process, to be described later.

53. Cutting Metals With Oxyacetylene Apparatus. The oxyacetylene torch is employed very successfully in the cutting of steel or wrought iron. The part of the metal surface to be cut is first heated either by an oxyacetylene or oxygas flame until a state of incandescence is reached, when a fine, powerful flame of oxygen alone is directed on the spot. The cutting torch resembles the welding torch in appearance, but has an additional pipe either inside of it or on the outside for the passage of the oxygen for the cutting jet. Immediate combustion commences with the formation of iron oxide, which is blown away by the pressure of the gas, leaving a narrow slot with clean-cut edges. The cut may be given any shape desired, curved or straight.

54. Blau Gas-Welding Processes.—Various other gases are used in connection with oxygen when welding, one of these being *Blau gas*, named after its inventor. **Blau gas** is a compressed, liquefied, distillation gas produced from mineral oils. In the Blau gas-welding system, both the oxygen and the Blau gas are bought compressed in steel bottles, which, together with a mixing tank, torches, and their appurtenances, comprise the system. The oxy-Blau gas system is used for the same purposes as oxyacetylene and has certain advantages. Blau gas is non-poisonous, has a small explosive range, and seldom flashes back. The oxy-Blau gas apparatus is compact and easily transported.

ELECTRIC WELDING

PRINCIPLES

55. Electrical Terms.—The flow of an electric current in a wire is, in many ways, like the flow of water through a pipe. If a pipe connects two vessels, one of which is placed much higher than the other, the water will flow from the higher to the lower, and will exert considerable pressure at the lower end of the pipe. It is this pressure, which is measured in pounds per square inch, that causes the water to flow. In the case of an electric current pressure is necessary to cause the flow; but this pressure is measured in **volts** and not in pounds.

The amount of water that flows through a pipe is usually measured in gallons, and the rate at which the water flows is measured by the number of gallons per minute. In the case of the electric current, the rate of the flow is measured in **amperes.**

56. When water flows through a pipe, the bends, valves, and rough sides of the pipe tend to prevent the flow. If a fine wire netting is placed over the end of the pipe, the flow is much reduced because the netting hinders the passage of the water. Likewise, the flow of electric current is hindered by the resistance of the wire. The smaller the wire, the

greater its resistance, just as a decrease in the size of a pipe will increase the resistance to the flow of water. The current will heat the wire, and the larger the number of amperes, the greater is the heating effect. By increasing the flow of current, the wire may be heated to its melting point.

Electric power is measured in **watts,** and is equal to the product of the rate of flow of current in amperes by the pressure of the current in volts; that is, watts = amperes × volts. One thousand watts equal 1 **kilowatt.**

57. There are two kinds of electric current in general use, *alternating* and *direct.* An **alternating current** is one in which the flow of the current changes from one direction to the opposite and back rapidly. A **direct current** is one that always flows in the same direction. The free end of a direct-current conductor from which, when the circuit is closed, the current flows is called the *positive terminal* and the end to which the current flows is called the *negative terminal.* An **electrode** is the end of a conductor from which the current flows to another electrode through a liquid or the air. A **switch** is a device for opening and closing the circuit.

58. Principle of Electric Welding.—The fact that the temperature of a body is raised by passing a current of electricity through it is the principle on which electric welding depends. The heating is greatest at the point where the resistance is greatest, which is at the contact surface between the ends of the pieces to be welded.

BERNARDOS ELECTRIC-WELDING PROCESS

59. One of the most common of the many different processes by which electric welding is done is the Bernardos process, in which the welding is accomplished by fusion. By means of the electric current, the parts to be welded are heated until they melt, when they flow together, no pressure being required.

The Bernardos process is one form of *electric-arc welding.* The classes of work handled by these processes are usually quite different from those to which the oxyacetylene process is

adapted; in fact, the processes may be said not to infringe on one another in any way, the electric processes being used for rough work, the oxyacetylene process for fine work.

60. Apparatus.—In the Bernardos process, the metal *a*, Fig. 18, that is to be welded constitutes the positive terminal of a direct-current electrical circuit and a carbon electrode *b* the negative terminal. In operating, the carbon is first brought in contact with the metal and then separated, thus striking the arc, which is then played upon the metal electrode. The temperature of the flame is between 6,500° and 7,000° F., and all metals can be melted in it.

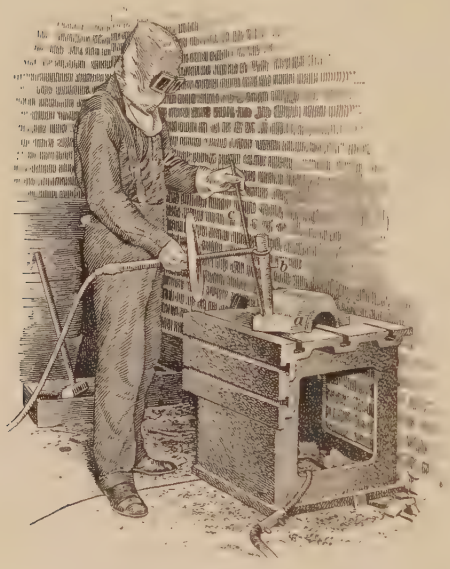


FIG. 18

The apparatus required consists of a source of direct current of the proper voltage, switches, resistances, carbon electrodes of various diameters, flux, material for filling cavities, covering for the head and hands of the operator, and an enclosure for the work.

61. Current.—The current for the Bernardos process must always be direct, not alternating, and while usually obtained from special dynamos, it may also be taken from public-supply mains. While the capacity of the dynamos may be for small work—as low as 15 kilowatts—250 amperes at 60 volts, it is better to be liberal in this respect; therefore, not less than 30 kilowatts is recommended. The pressure may vary from 60 to 100 volts; but in the latter case it must be reduced

somewhat when welding by inserting resistance in the circuit, the higher voltage only being necessary for cutting.

62. Controlling Apparatus.—One of the most common working arrangements of the circuit is shown in Fig. 19. The current from the lead *a*—that is, the wire through which the current flows—passes through the steel terminal plates *b* immersed in barrels of water *c*, through the water, and thence through the wire *d* to the metal table *e* and casting *f* to be welded. The other lead *g* connects directly with the carbon electrode *h*. A *voltmeter*, an instrument that measures voltage, and an *ammeter*, an instrument that measures amperes, are generally placed in the circuit to indicate the voltage and the amperes of the current that are being consumed. A circuit-breaker is usually placed in the circuit to break the circuit

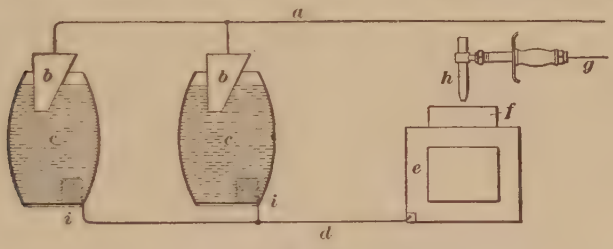


FIG. 19

if the current should become greater than desired. The steel castings *i* serve as weights to hold steel plates down in the barrel. The leads are connected to the steel plates. The controlling apparatus consists of the terminal plates *b* and the water barrels *c*. These terminal plates may be raised or lowered at will, raising them increasing the resistance and decreasing the voltage at the electrodes, and lowering them decreasing the resistance and increasing the voltage at the electrodes.

The water in the barrels will boil over occasionally, necessitating a temporary stop in the work to allow the water to cool or be renewed. For this reason, instead of controlling the apparatus with the resistance offered by the water, cast-iron resistances are often employed, the principle being the same.

63. Carbon-Electrode Holder.—Fig. 20 shows a common type of holder for the carbon electrode used in the Bernardos process. It consists of a piece of pipe *a* threaded and split at one end *b* to receive the eyepiece which holds the electrode and over the other end of which is fitted a wooden handle *c* with a protecting shield *d* of fiber or asbestos. The electrode *e* is driven lightly into a special metal eyepiece *f*, which, in turn, fits into the threaded pipe, being firmly held by a nut *g*. The sizes of the carbon electrodes will vary from $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches in diameter; they are about 6 inches in length and should be made solid, and preferably of graphite.

64. Covering for Operator.—Owing to the intense brightness of the arc in the Bernardos electric-welding process, the operator must be well covered, not only about the head, but

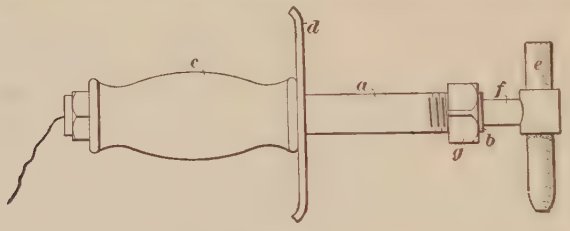


FIG. 20

over the hands and the body as well. Exposure to the rays for even a few moments will result in sunburning the exposed surfaces, with the subsequent irritation and peeling of the skin, though fortunately with no other serious consequences. The clothing will be sufficient covering for the body; the hands may be protected by gauntleted gloves, and a hood of canvas, wood, or sheet iron, fitted with a small projecting window of colored glass, should be worn to protect the eyes. The glass should be of several thicknesses, blue and red forming the best combination.

65. Flux and Filling Material.—Electric welding may largely be done without any flux whatever. Borax is, however, very good, especially if the water of crystallization has been removed. Removal of the water may be readily accomplished

by heating the borax in a crucible of graphite until bubbling has ceased, then allowing it to cool and crushing it. The purpose of the borax is simply to cover the melted surface of the metal with a thin film, thus keeping the air from it, and preventing oxidation. An excellent flux for the general run of work in cast, wrought or malleable iron and steel consists of a mixture of 75 per cent. of borax and 25 per cent. of red oxide of iron. Any carbon that has entered the weld from the electrode unites with the oxygen in the flux and is burned, leaving pure iron in its place. Should the gas not be entirely dissipated, the metal will show a fine, spongy appearance, which, however, can be largely removed by hammering the metal while still white hot.

The material used to fill the openings in the work to be welded is known as *filling material*. When welding steel, wrought, cast or malleable iron, the filling material may be soft Norway or Swedish iron rod, boiler-plate scrap, or bits of steel castings, though for cast and malleable iron, a special cast iron with a high percentage of silicon is recommended.

66. Making a Weld.—In making a weld by the Bernardos process, the piece to be welded may be connected either directly to the terminal, or laid on the metal table shown in Figs. 18 and 19, if one is used. The resistance in the circuit should next be adjusted by raising or lowering the terminal plates if water barrels, Fig. 19, are used, or by closing the proper switch if grids are employed. The circuit-breaker should next be closed and finally the single-pole switch. With the flux and the filling material close by, the operator now places himself in the proper position, taking the carbon electrode in one hand and pulling the head-gear over his head with the other. The carbon electrode is next touched to the metal and immediately pulled away again, thus closing the circuit and striking the arc. A rotary motion is then given to the arc so that the metal in the vicinity of the weld will also be heated, thus facilitating the work. The arc should be fairly long, from 2 to 4 inches, as in this case particles of carbon are less likely to find their way into the molten metal. If the arc proves troublesome, either by going out or by being too violent, the resistance in the circuit

should be decreased in the first instance or increased in the second. After the metal commences to boil, small quantities of flux and filling material should be added from time to time, the arc being stopped only long enough to allow them to be added. When soft-iron rods are used for filling material, they are sometimes first dipped in a paste made of the flux mixed with water which is allowed to dry on the rods. The operator then feeds the rod *c*, Fig. 18, directly into the weld, the arc being played on the end and so causing it to melt and at once become a part of the boiling mass. The instant welding ceases, the weld should be hammered to give the metal a closer texture or grain, as well as to eliminate sponginess.

67. Not only must precautions be taken to start with clean cavity and clean materials, but throughout the operation all dirt must be kept away. Before commencing to weld, therefore, the cavity should be chipped clean. This cleaning may be accomplished with the aid of the arc by placing the piece in such a position that when the arc is played upon it, gravity will cause the molten slag to drop free. As oxide of iron or scale readily forms on exposure of the heated metal to the air, the weld should be made, whenever possible, by a single application of the arc. Preliminary heating of the metal is not essential with wrought iron or steel, but is almost always advisable with cast or malleable iron. Annealing after welding is strongly recommended in all cases, if soft welds are to be obtained. One of the greatest criticisms of the Bernardos process of arc welding is that the welds are sometimes so hard as to make machining impossible. When this proves to be the case, the only solution is to remelt and remake the weld.

68. When building a projection or lug on a casting it is usually necessary to make a retaining wall of fireclay to hold the molten mass. When welding brass, the piece should be carefully supported and the arc applied but intermittently, otherwise warping will take place. Welds made by the Bernardos process may be taken as averaging 70 per cent. of the strength of the original material. As in oxyacetylene welding, the section

of the metal at the weld may sometimes be increased over that of the other portions, thus compensating for its lesser strength.

69. Cutting of Metals.—The Bernardos process may be used for cutting work of the rougher kinds, as in cutting away surplus metal, such as the sink heads on steel castings, for opening the tap holes in iron cupolas, etc. About the same methods are employed as in welding, except that the current and voltage are usually higher, sometimes 800 to 1,200 amperes at 100 or more volts.

THOMSON ELECTRIC-WELDING PROCESS

70. Another method of electric welding is by the *incandescent process*, in which the ends of the pieces to be welded are brought to a welding heat by passing a large current through them, and when they are heated pressing them together firmly, thus forming the weld. The heating power of a current depends on the rate of flow, or the number of amperes. In electric welding, the pressure may be only a few volts or even a fraction of a volt, while the current is large; that is, a large number of amperes is required to obtain the necessary heating effect. The **Thomson electric-welding process** is one form of incandescent electric welding.

71. Apparatus.—An electric-welding machine is used for welding by the Thomson process. This machine holds the pieces to be welded, provides means for heating them by the electric current and for forcing them together to form the weld. A welding machine used in welding flat iron hoops, shown in Fig. 21, consists of a heavy cast-iron base a that supports two bronze clamps b, c, which are operated by the handles d and e. The clamp b is fixed, but the clamp c can be moved toward the clamp b by means of the lever f. Water flows through the pipes h into the clamps, which are hollow, and prevents them from becoming overheated. The rubber tube h' allows water to circulate from one clamp to the other, and permits the clamp c to be moved, which could not be done if h' were a solid pipe.

Since water and iron are both conductors of electricity, a small part of the current will flow from one clamp to the other

through the water in the tube h' and through the lower solid part of the hoop. But since the resistance along each of these paths is much greater than that directly between the clamps, the small amount of current thus lost does not affect the action of the machine. By changing the form of the clamps, this machine can be used for other classes of work.

72. Making a Joint.—To form a weld by the Thomson process, the ends of the hoop are fixed firmly in the clamps,

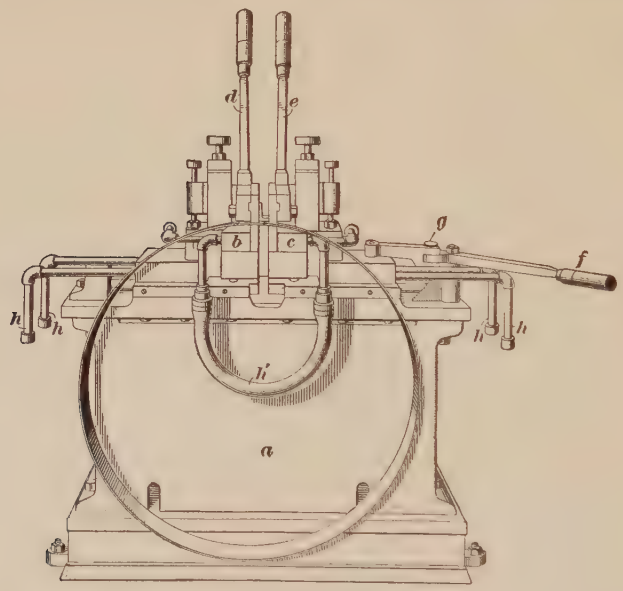


FIG. 21

as shown, the ends are then brought together, and the current is turned on. The current passes into one end of the hoop from the clamp b, Fig. 21, across the minute air gap between the ends of the hoop, and then back through the clamp c. But the resistance of this small air space, or gap, between the ends is great enough to bring the metal ends to a welding temperature. As soon as the welding temperature is reached, the lever f is pulled toward the left, when the joint at g straightens and moves the clamp c to the left. The two ends are thus forced together and the weld is completed.

RIVETING

73. Hand Riveting.—It is often desired to fasten together two pieces of iron or steel by riveting, as, for example, in joining the plates that form a steam boiler. Holes are punched or drilled through both pieces, and a *rivet*, which is a pin having a head at one end, is put through both holes. The small end of the rivet is then upset so as to form a second head. Riveting may be done cold, but if a tight joint is required the rivet is heated and headed while red hot; in cooling, it will contract and draw the heads together, thus making the joint tighter.

74. The rivet holes in plates are generally punched; this makes them slightly tapered, and if two punched plates are joined the holes may come together in any one of three ways, as shown in Fig. 22 (*a*), (*b*), and (*c*). If the rivets are hot enough, they will readily upset so as to fill the holes in any case; but passing them through the cold plates frequently chills them so that they will not upset properly. For this reason, when the holes are not in line, they should be smoothed with a *drift pin*, or, better still, reamed out after the plates have been clamped in position, as shown in (*d*). The reaming also removes some of the injured metal from the sides of the holes. The *drift pin* is a smooth, slightly tapered pin that is driven into the holes to expand them in places where they are too small, thus giving them an even taper. The reamer gives the same result by cutting away the rough edges of the hole. Drifting strains or distorts the metal, and should never be done on any riveted joint that must bear a heavy load. The hot rivet is put in the hole, and a heavy piece of iron or a hammer is held against the head while the other head is being formed. The body of

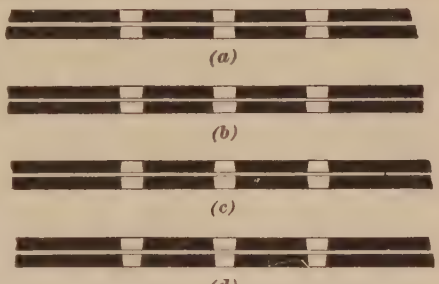


FIG. 22

the rivet should completely fill the holes in the plates after the rivet is headed.

75. Machine Riveting.—Where a large number of rivets are to be headed, the work is done by machine, which does it much faster and better than it can be done by hand, because the rivet is headed before it has had time to cool. The hammer of the riveting machine is sometimes driven by compressed air at the rate of several hundred blows per minute, the rapidity of the blows being more necessary than their force. In forming the head, quick blows with a light hammer upset and spread the iron, while heavy blows tend to bend it. Another form of riveting machine presses the end of the rivet into a head by forcing a forming die against it. This machine is operated by compressed air or by water pressure, and gives satisfactory results, as the flow of the metal under the heavy pressure completely fills the rivet holes. In taking riveted plates apart, it is better to drill the rivets out than to drive them through, since it is less liable to injure the plates.

BENDING BRASS AND COPPER PIPE

76. Annealing Brass and Copper Pipe.—Whenever a piece of brass or copper pipe or tubing is to be bent or shaped, it must be first annealed, which should make it so soft that the smaller sizes can be bent by hand. This *annealing*, or softening, is done by heating the metal evenly to a dull-red heat and then plunging it in cold water.

77. Bending Small Tubing.—The simplest way to make a bend in a small tube is to turn a block of hardwood to the radius of the desired curve and then bend the pipe about the block. When the radius is small, this may be done as shown in Fig. 23, *a* being the block about which the pipe is to be bent and *d* a square block of the same thickness, clamped in a vise *b*, so as to hold the end of the pipe during the bending. After the two blocks *a* and *d* are so placed that the pipe can just be slipped between them, the end of the pipe *c* is slipped through

to the point where it is desired to form the bend, and the other end is carried around, as indicated by the dotted lines, to the desired angle. If a greater bend than 180° is made, it is sometimes difficult to remove the wooden block from the tubing.

In some cases, a groove is turned about the block *a*, the radius of the groove being equal to the radius of the outside of the pipe, so that the pipe will bed istelf in the groove while being bent. This process aids in keeping the pipe from flattening. This simple device will serve to bend pipe up to $\frac{3}{4}$ inch in diameter, and is sometimes used for larger sizes.

78. Support of Tubing During Bending Process.—To prevent the tubing from kinking or flattening while being bent, the inside must be filled with some substance. Sometimes, when there is a thread on each end of the tube, it is filled with sand and a cap screwed on each end; or the tube may be filled with water and the ends capped. When water is used as a filling material, care must be taken to fill the pipe completely, for if it contains any air the latter may be compressed and allow the pipe to flatten at some point. The more common practice is to fill the tube with melted resin and allow this to harden. During bending, the resin will be pulverized, but it will prevent the tube from flattening. After the bend is made, the resin can easily be melted and run out. Pipes less than $\frac{5}{8}$ inch in diameter are bent without filling. Occasionally, if the metal is thick, larger pipes may be bent in this manner, but no risk should be taken if a good bend is required.

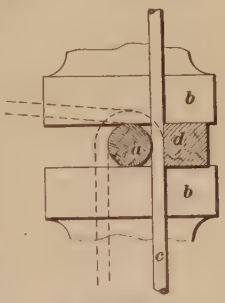


FIG. 23

79. Bending Large Tubing.—To bend large tubes, a special device like the one shown in Fig. 24 is used. It consists of two wheels *a* and *b* arranged as shown. The wheel *a* is clamped in a vise or by means of a special clamp. If it is required to bend greater angles than 90°, the vise or clamp must be so located that the lever *c* can make the desired portion of a revolution. The lever *c*, which is forked at the end

and carries the wheel *b*, is pivoted to the pin *g* passing through the center of the wheel *a*. Attached to the wheel *a* is a clamp *d* that holds the tube in its proper position. The radius of the wheel *a* must be equal to that of the desired curve, and the outside of each wheel is turned to such a form that when the wheels are in position they barely allow the tube to pass between them, which prevents any tendency of the metal to flatten or buckle. The clamp *e* is placed on the tube, so that it will locate the point at which the bend is to begin. After the tube is in place,

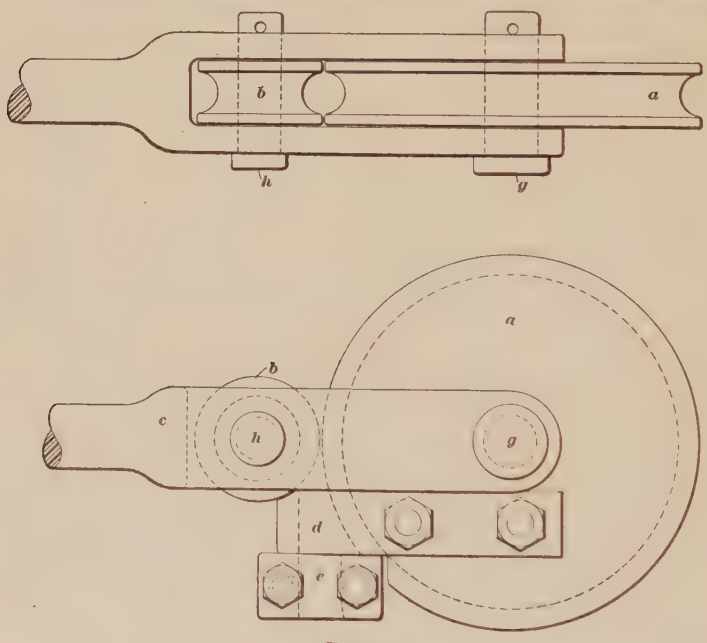


FIG. 24

the lever *c* is carried around the wheel *a* and the bend is formed. To remove the bent tube, the pin *h* may be taken out to allow the removal of the wheel *b*; or the pin *g* may be removed, thus allowing the entire lever *c* to be taken away from the wheel *a*. The radius of the larger wheel *a* is made from $\frac{1}{32}$ to $\frac{1}{16}$ inch less than that of the corresponding radius of the pipe, to allow for the spring when the pipe is released. The wheel *b* is made as small as the stresses on it will permit.